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"When we try to pick out anything by itself, we find it hitched to everything else in the Universe."

John Muir, 1911

University of Alberta

Native Forb Establishment on Disturbed Sites in the Aspen Parkland

by

Catherine Jean Erichsen Arychuk ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

Department of Renewable Resources

Edmonton, Alberta

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Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Native Forb Establishment on Disturbed Sites in the Aspen Parkland" submitted by Catherine Jean Erichsen Arychuk in partial fulfillment of the requirements for the degree of Master of Science.

Dedication

To Kevin: for your encouragement, your support and your constant faith in me.

Abstract

Establishment, survival and reproduction of native forbs introduced onto disturbed sites in the aspen parkland were studied for two years. Forbs were either broadcast seeded or nursery grown seedlings transplanted onto sites. Effects of location, season of introduction and weed control by mowing were assessed in a complete randomized split block design. Location and previous site management changed seedbank and plant invasion potential, significantly affecting native forb seedling and transplant survival. Competition from low-growing perennial weeds reduced establishment and survival of both seeded and transplanted forbs. Mowing, which removed annual weeds, reduced establishment and survival of seeded native forbs but did not affect transplanted forbs. Spring seeding or planting increased survival of both seeded and transplanted forbs. However, fall seeded or planted forbs matured and set seed sooner. With proper management, both seeding and transplanting introduced native forbs onto disturbed sites at a rate of at least one plant m^{-2}.

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CHAPTER 1 LITERATURE REVIEW

1.1 REVEGETATION IN ALBERTA

Interest in using native plant species is rapidly increasing. Native plant species, for this research, are defined as those plants indigenous to an area and present before European settlement (Gerling et al. 1996). On the Canadian Prairies native species are being used to reclaim a growing number of industrial disturbances. Much of the emphasis on native species is based on changing social values and policy shifts, as well as advances in ecological knowledge (Roundy et al. 1997, Richards et al. 1998).

Historically, revegetation goals focussed mainly on soil conservation, watershed management and forage production for domestic livestock. Early revegetation studies, particularly in the United States, tested many native species, but found problems with adaptation to site or climate, establishment and seed production (Roundy et al. 1997). Revegetation using agronomic plant species accomplished the objectives of the time. These grass and legume species were widely adapted, could be easily and rapidly established, competed with weeds, controlled erosion, stabilized soil and provided forage for livestock. They were also considerably cheaper to produce and purchase.

Sites revegetated with agronomic forage species are not always compatible with surrounding native vegetation. Areas seeded to agronomic forages do not look or function like surrounding native vegetation and may not allow native species to move back into the system (Gerling et al. 1996, Lesica and DeLuca 1996). Agronomic species may invade adjacent native vegetation (Smreciu 1994). Some agronomic species do not maintain or rebuild soil as effectively as native species (Dormaar et al. 1994).

Recent government and public values have shifted public land use and associated revegetation goals from a commodity production focus to a multiple use, biodiversity and ecosystem management focus. Native plant species are considered critical to maintaining and restoring genetic and ecological integrity of native ecosystems (Richards et al. 1998). Current use of native plant species for revegetation varies. In Alberta, government agencies have required native species for reclamation of native prairie on public land in southern and eastern Alberta since the early 1990s (Gerling et al. 1996). Use of native species on public lands in the rest of the province is increasing. Some cities, schools and

municipalities are using native species in roadside, schoolyard and park plantings.

Several native grasses are commonly used for reclamation in Alberta. However, reclamation success may be improved by using a mix of species, which includes plants with different phenological traits and life histories (Brown and Chambers 1989). A range of species will ensure stand survival during extreme events such as drought or floods. Native forbs (broad-leaved non-woody plants) improve community and soil stability on reclaimed sites and improve aesthetics (Currah et al. 1983). They provide food and shelter for wildlife and increase plant species diversity. Yet they are seldom used in reclamation because seed supply is limited, seed is expensive, seed germination can be low and little information is available on establishment on industrial sites (Blake 1935, Sorensen and Holden 1974, Voight 1977, Bjugstad and Whitman 1989). Research on native forbs for reclamation is limited. Currah et al. (1983) considered the reclamation potential of native wildflowers in Alberta virtually unexplored. Gerling et al. (1996) and Pahl and Smreciu (1999) recently published information on some native forbs for reclamation.

1.2 Role of Native Forbs in Plant Communities

In most communities forbs comprise a small proportion of the plants (Sorensen and Holden 1974, Bjugstad and Whitman 1989). However, up to 40% of cover in grasslands may consist of these broad-leaved wildflowers (Currah et al. 1983). Although many communities have a higher density of grasses than forbs, forb species usually outnumber grass species. Forbs are an important part of native prairie ecosystems and are present in all range condition classes including climax (Cook 1983). They add diversity to the community (Bjugstad and Whitman 1989, Gerling et al. 1996), enhance ecosystem structure and provide niches for other life forms. They increase ecosystem function by protecting soil from erosion and contribute to nutrient cycling.

Native legumes such as purple prairie clover and wild vetch (*Vicia americana* Muhl.) form symbiotic associations with rhizobial bacteria to convert atmospheric nitrogen into a plant-available form (Currah et al. 1983, Smreciu 1993), reducing the necessity for commercial fertilizers (Miller and Heichel 1995). Rhizobial bacteria

symbiosis has been widely studied in agronomic legumes. For these species, there is some specificity of rhizobial bacteria strains and those that are most effective and efficient for each plant species have been selected and are available commercially (Miller and Heichel 1995, Pahl and Smreciu 1999). Inoculation with the appropriate bacterial strain increases nitrogen fixation in agronomic legumes. At present, no rhizobia strains have been developed for native legumes (Pahl and Smreciu 1999).

Nitrogen can be fixed by several non-nodulated plants (Dobereiner and Day 1975, Neyra and Dobereiner 1977, Rennie et al. 1983). McKone and Biesboer (1986) found that Canada goldenrod (*Solidago canadensis* L.) and stiff goldenrod (*Solidago rigida* L.) fixed atmospheric nitrogen. Stiff goldenrod was more effective than Canada goldenrod and neither species was as efficient as legumes, but McKone and Beisboer (1986) concluded both might provide a nitrogen source for other plants.

Many legumes have long taproots that can use water and nutrients from deeper in the soil profile than grasses (Smreciu 1993). Purple prairie clover (*Petalostemon purpureum* (Vent.) Rydb.), long-fruited anemone (*Anemone cylindrica* A. Gray), prairie coneflower (*Ratibida columnifera* (Nutt.) Woot. & Standl.) and yellow puccoon (*Lithospermum ruderale* Lehm.) all have deep tap roots (Currah et al. 1983) and increase the availability of soil nutrients in the upper portion of the soil profile over time.

Many forbs form active associations with arbuscular mycorrhizal (AM) fungi (Currah et al. 1983, Currah and Van Dyk 1986). These are abundant in soils of most native ecosystems and form mutualistic symbiotic associations with the roots of 80% of plant species (van der Heijden et al. 1998). Fungal hyphae act as extensions of the plant root system (Follett and Wilkinson 1995, van der Heijden et al. 1998) increasing effective root surface area, improving the plant's ability to absorb and translocate nutrients, especially relatively immobile nutrients like phosphorus (Hetrick et al. 1986, Marschner and Dell 1994, Follett and Wilkinson 1995) and increasing water scavenging ability (Sylvia et al. 1993, Dhillion and Friese 1994, Follett and Wilkinson 1995). Yost and Fox (1979) found that at low soil levels, plant uptake of phosphorus was 25 times greater with mycorrhizal associations than without. Mycorrhizal associations with legumes in low phosphorus soil also increased nitrogen fixation (Follett and Wilkinson 1995).

Many native forbs and some native grasses are actively mycorrhizal (Pahl and

Smreciu 1999). Little work has been done to isolate fungi associated with specific native forbs. Although few fungal strains are available commercially, their introduction into reclamation sites when seeding native plants may increase revegetation success. Topsoil from native sites often contains the fungi necessary to form these associations (Pahl and Smreciu 1999). However, soil disturbance and topsoil storage reduces the number of propagules present (Miller 1979, Moorman and Reeves 1979, Harris et al. 1993), as do drought, erosion and grazing (Allen 1989). Annual cropping of agricultural land decreases fungal diversity and may reduce plant biodiversity and community stability (Johnson 1993, Helgason et al. 1998). Smith et al. (1998) found road construction disturbance of soils in tallgrass prairie greatly reduced mycorrhizal populations and inoculating the site with AM propagules enhanced growth of mycorrhizal-dependent warm season grasses over cool season grasses.

Mycorrhizal fungi may be required to maintain a basic level of plant biodiversity (van der Heijden et al. 1998). Changing composition and number of fungal taxa will change structure and composition of the native plant community since plant productivity and diversity are dependent on a diversity of fungal species (van der Heijden et al. 1998). Plant species diversity on cool season grass communities was increased by the presence of mycorrhizae (Grime et al. 1987). AM fungi particularly affect plant communities where non-mycorrhizal plants are competing with obligate mycorrhizal plants, such as warm-season grasses (Reeves et al. 1979, Hartnett et al. 1993, Wilson and Hartnett 1997).

Many native forbs contribute forage value to a site. Cook (1983) found domestic cattle and sheep grazing on native pasture used 65 of 81 forb species present. Species like purple prairie clover, wild vetch and smooth aster (*Aster laevis* L.) are grazed by domestic animals (Gerling et al. 1996). Wild ungulates and other wildlife also consume these species, as well as others like the goldenrods (*Solidago* spp.) (Gerling et al. 1996). Forbs often contain higher levels of protein, phosphorus and other minerals and vitamins than grass species (Cook 1983, Klebesadel 1971). They generally mature later than grasses and maintain higher nutrient levels longer into the summer and fall (Cook 1983). Purple prairie clover, for example, contains high levels of protein (Stubbendiek et al. 1993). Forbs provide a valuable forage source for wildlife, particularly in spring and fall. Native forbs also provide cover and nesting material for wildlife (Zajicek et al. 1986).

Native forbs add aesthetic appeal to a reclaimed landscape by providing contrast, color and interest. Many are pioneer species and help rehabilitate disturbed sites by preventing soil erosion and improving nutrient cycling (Salac and Hess 1975, Zajicek et al. 1986, Bjugstad and Whitman 1989). Native forbs help blend the disturbed site into the surrounding undisturbed vegetation, speeding achievement of reclamation goals.

Forbs play important roles in native plant communities. To date, many native plant revegetation projects have focussed only on native grass species. Research on introduction of native forbs and the appropriate establishment methods is needed.

1.3 Adaptations of Native Forbs

Seeds of native prairie plant species, including forbs, have adaptive mechanisms to help them survive stressful conditions. Most prairie species are long-lived perennials. Many produce numerous seeds, but few germinate at any given time in harsh environments. Many seeds have high dormancy and remain in the seed bank until conditions are appropriate for germination. Many species also reproduce vegetatively by tillers and rhizomes to avoid poor germination conditions.

Seeds of many native forbs are adapted to germinate in spring when conditions are most favorable for survival. Seed germination is often very low immediately after harvest (Blake 1935, Young and Young 1986). An after-ripening period of one to three months following harvest may increase seed germination in some species (Young and Young 1986). This after-ripening requirement is an adaptive feature for prairie plants and protects seeds that mature in mid to late summer from germinating in early fall when moisture and temperature conditions make survival less likely. Germination of many native seeds increases gradually from very low at harvest time to a maximum in mid-spring (Blake 1935). Germination decreases over summer, rising again in early fall.

High seed dormancy and poor germination in native forbs presents a management problem when using these species for revegetation. Appropriate seed production, handling and establishment techniques should help to reduce these problems.

1.4 Use of Forbs in Reclamation

Legumes are considered keystone species and many reclamation seed mixes, even those using native grasses include at least one agronomic legume to fix nitrogen (Munshower 1994). The assumption is that agronomic species will be displaced from the plant community by native plants. However, this may not happen. Native legumes may be a better choice since they are normal constituents of the surrounding plant community. However, native legumes can be more difficult and expensive to establish.

The most common method of establishing native forbs on reclaimed sites is by seeding at the same time as grasses (Salac and Hesse 1975, Zajicek et al. 1986). However, native forbs are generally considered hard to establish from seed. Common causes of establishment failure include improper seeding techniques, insufficient seeding rates, poor seed germination, inability of forb seedlings to compete with grasses and improper management (Zajicek et al. 1986). Germination of native forb seed varies greatly with species, but field germination and survival rates are generally low and emergence is slow (Currah et al. 1983, Wallace et al. 1986, Bjugstad and Whitman 1989).

1.4.1 Establishment of Native Forbs from Seed

1.4.1.1 Seed Germination

Seeds germinate in four stages (McDonough 1977). The first stage, imbibition, is the uptake of water, mainly by proteins in the seed. This results in hydration and activation of nucleic acids and enzymes. The next stage is cell enlargement and division. The final stage, recognizable germination, is when the root grows through the seed coat.

Emergence of native forbs from seed occurs slowly. Bjugstad and Whitman (1989) found many species, including white prairie clover (*Petalostemum candidum* (Willd.) Michx.), purple prairie clover, wild blue flax (*Linum lewisii* Pursh), velvety goldenrod (*Solidago mollis* Bartl.) and prairie coneflower required up to 120 days for seedling emergence. Seedlings of harebell (*Campanula rotundifolia* L.), prairie sunflower (*Helianthus rigidus* (Cass.) Desf.) and narrow leaf beardtongue (*Penstemon angustifolius* Pursh) did not emerge in these trials. However, Blake (1935) found that seed for half the native forbs tested, including woolly yarrow (*Achillea occidentalis* DC.),

Canada milkvetch (*Astragalus canadensis* L.), dotted blazing star (*Liatris punctata* Hook.), yellow evening primrose (*Oenothera biennis* L.) and goat's beard (*Tragopogon pratensis* L.) germinated within two weeks. The other half, including *Aster salicifolius* Ait., pale purple coneflower (*Echinacea palida*), wild licorice (*Glycyrrhiza lepidota* (Nutt.) Pursh), prairie sunflower, *Petalostemon* species and *Solidago* species, generally germinated within two to four weeks. Long-fruited anemone, many-flowered aster (*Aster multiflorus* Ait.), and tall gayfeather (*Liatris scariosa* (L.) Willd.) needed four to six weeks for germination. Sorenson and Holden (1974) also found that seed for many native species could be successfully germinated.

Growing conditions during seed production influence forb seed germination (Blake 1935). Drought lowers germination, while cool temperatures and above normal rainfall increase it. Often, seed of native species grown in natural or wild conditions has poorer germination percentages and rates than seed of the same species raised in garden or agronomic conditions (Blake 1935, Salac and Hesse 1975). Timing of native forb seed harvest impacts seed germination (Voight 1977). If harvested too soon, seed embryos will be immature. If harvested late, early maturing seed may have been dispersed. Insect and fungal damage reduces seed germination. Blake (1935) found very low seed germination rates for wild collected native forbs. Germination rates for seed raised under more controlled growing conditions are of less concern (Sorenson and Holden 1974).

Germination of many native forbs can be improved with seed treatments that vary with species. Some species, often those that set seed in early summer, have no after-ripening requirement and germinate best when freshly harvested (McDonough 1977). By spring, many native forbs germinate well without treatment. In South Dakota, Sorensen and Holden (1974) found 16 of 23 native forbs studied germinated without pretreatment, indicating no problems for commercial use. These included common yarrow (*Achillea millefolium* L.), long-fruited anemone, silky aster (*Aster sericeus* Vent), daisy fleabane (*Erigeron strigosus* Muhl) and three flowered avens (*Geum triflorum* Pursh).

Moist-cold seed treatment (stratification) improves germination of some native forbs (Sorensen and Holden 1974). This treatment involves placing seed on a moist medium and storing in a cold (3 °C) place for one to three months (Hartman et al. 1997). Moist-cold treatment is often used to break temperature dependent seed dormancy

(Mayer and Poljakoff-Mayber 1975, McDonough 1977, Hartman et al. 1997). The treatment imitates natural prairie growing conditions, where dispersed seed lies in cold, moist ground over winter (Young and Young 1986). Fall planting is often used to enhance germination of dormant seeds but does not necessarily satisfy moist-cold requirements of seeds. This requires uninterrupted cold periods with temperature above freezing, when the seed stays moist but not saturated for two weeks to a month. During moist-cold treatment embryonic growth or metabolic changes speed seed germination (Mayer and Poljakoff-Mayber 1975, McDonough 1977, Hartman et al. 1997). In some species, seeds do not germinate because oxygen does not diffuse through the seed coat (Young and Young 1986). At cool temperatures, oxygen is more soluble in water so oxygen requirements of the embryo are better satisfied. Sorensen and Holden (1974) found that of 13 species of native forbs subjected to moist-cold treatment, 30.7% germinated only after cold treatment, 23.1% had increased germination rates with treatment, 15.3% were not affected by treatment and 30.7% had reduced germination.

Sorensen and Holden (1974) found moist-cold seed treatment improved germination of tall cinquefoil (*Potentilla arguta* Pursh), pussytoes (*Antennaria* spp.) and alexander (*Zizia* spp.). Treatment increased percentage of seeds that germinated and rate of germination. Moist-cold treatment of long-fruited anemone did not affect the percentage germination, but increased rate of germination. Blake (1935) found moist-cold treatment improved germination of 20 of 26 native forbs. Species improved were woolly yarrow, pussytoes (*Antennaria campestris* Rydb.), many-flowered aster, *Aster salicifolius*, pale purple coneflower, prairie sunflower, white prairie clover, tall goldenrod (*Solidago altissima*), low goldenrod (*Solidago missouriensis* Nutt.), and blue-eyed grass (*Sisyrinchium angustifolium* Miller). In a second test of ten forbs, treatment increased germination for six (groundcherry (*Physalis lanceolata* Michx.), woolly verbena (*Verbena stricta* Vent.), ironweed (*Vernonia baldwini* Torr.), Canada goldenrod, false boneset (*Kuhnia glutinosa* Ell.) and tall gayfeather). The other four species were unaffected by treatment. Treatment reduced germination of daisy fleabane (Sorenson and Holden 1974), dotted blazing star, false boneset, longbearded hawkweed (*Hieracium longipilium* Torr.) and leadplant (*Amorpha canescens* Pursh) (Blake 1935).

For early and abundant spring germination, Blake (1935) recommended very late

fall sowing for most forbs. Moist-cold seed treatment is recommended for harebell and low goldenrod (Currah et al. 1983, Gerling et al. 1996). Some researchers recommend moist-cold stratification for common yarrow and three flowered avens (Currah et al. 1983), while others found this treatment is ineffective or reduces germination in these species (Sorenson and Holden 1974, Young and Young 1986).

Blake (1935) found that freezing dry seeds in storage increased germination of several forbs, including woolly yarrow, leadplant, roundheaded bushclover (*Lespedeza capitata* Michx.), tall gayfeather and *Petalostemon* species. However, Young and Young (1986) found dry seeds rarely demonstrated enhanced germination as a result of chilling.

Many forb seeds need radiation stimulation to germinate (Sauer and Struik 1964, Wesson and Wareing 1969, Florez and McDonough 1974, McDonough 1977). Light can promote or inhibit germination, depending upon the species (McDonough 1977). Light stimulation or inhibition of germination is an adaptation for survival. These seeds do not germinate if they are too deep for the seedling to emerge or too near the surface with the risk of temperature and soil water extremes. A light requirement for germination is more common in species with small seeds and a high surface area to volume ratio. Young and Young (1986) found that exposure to light increased germination of common yarrow.

Some seed dormancy is caused by a hard seed coat, usually a multi-layered membrane around the seed (Mayer and Poljakoff-Mayber 1975). The coat may be impermeable to water or gases, or may physically prevent emergence of the embryo. In nature, alternation of extreme temperatures, microbial action and abrasion against soil particles gradually erode the seed coat and increase permeability (McDonough 1974). Scarification to break the seed coat may improve early germination rates (Young and Young 1986) and is commonly done by mechanical abrasion or soaking seeds in an acid solution. Many species in *Leguminosae* and *Malvaceae* have hard seeds (McDonough 1974). The hard seed coat adaptation allows seeds to survive for a number of years in the soil, spreading their germination over time. Sorenson and Holden (1974) found that prairie coneflower had a seed membrane impervious to water and gases, resulting in seed dormancy. Seed germination increased when the seed coat was punctured. They also found that scarification increased seed germination of leadplant, Canada milkvetch, ground-plum (*Astragalus crassicarpus* Nutt.) and *Petalostemon* species. Scarification is

recommended for wild vetch and purple prairie clover (Sorenson and Holden 1974, Currah et al. 1983, Pahl and Smreciu 1999).

Seed treatments are often impractical to apply in the field. Forb seeds will usually need to be stored for a period of time prior to seeding. Hard seed coats can be scarified prior to planting, but this process should be done fairly close to the time of seeding and can cause seed storage concerns, as well as additional expense. Moist-cold seed treatments are impractical prior to field seeding. In practice, late fall seeding is often used with the expectation that this will improve germination.

1.4.1.2 Emergence, Growth and Seed Production

In the natural environment of many native species, moisture is often the most limiting factor. After a native seedling germinates, the root grows rapidly and penetrates deep into the soil where moisture is likely to remain available. The root of many native species elongates before the shoot appears above ground, sometimes even before it comes through the seed coat (Blake 1935). Many native forbs have an unbranched taproot that extends several centimeters while the cotyledons are unfolding (Blake 1935). The root often develops lateral branches before the shoot is exposed and subject to water loss.

Native seedlings develop vegetative propagation organs (rhizomes or other shoots) abundantly during the first year if conditions are favorable (Blake 1935). In all developmental stages, growth of foliage is slow and small relative to that of underground parts. Seedlings that had developed to the third or fourth leaf stage in the fall generally had 80 to 100% survival through the winter due to strong root development (Blake 1935).

Native forb seedlings grow slowly (Blake 1935) and face increasing competition from weeds and grasses when they emerge. Howell and Kline (1994) found competition from weeds and grasses reduced germination and establishment success of purple prairie clover. Weed competition had a greater impact than grass competition. Goldberg and Werner (1983) found growing conditions at germination and the following month critical to subsequent seedling survival and growth. Litter reduced emergence of Canada and sharp-toothed goldenrod (*Solidago juncea* Ait.) seedlings. They speculated that reduced emergence was due mainly to low light availability to seedlings, although impedance to seedling growth from litter, fungal infections encouraged by dark, moist conditions and

chemical inhibitions could have contributed. Many native forbs that develop readily into good stands also reproduce vegetatively (Salac and Traeger 1982).

Sorenson and Holden (1974) and Bohnen and Hanchek (1994) found when raised under controlled conditions, forb seed set was greater than in the wild. Blake (1935) found many prairie species that bloom their third or fourth year could, under cultivated conditions, bloom and set viable seed the first year. Growing conditions during seed maturation influence dormancy and germination (Mayer and Poljakoff-Mayber 1989). Producing native seed under cultivated conditions can increase desirable characteristics but can also increase the risk of loss of genetic diversity through inadvertent selection.

1.4.2 Establishment of Native Forbs by Seeding

1.4.2.1 Seeding Methods

Seed placement is critical to stand establishment. Seeds must be placed in the soil at a depth most favorable for germination and successful establishment (Munshower 1994). This optimum depth varies with species. In general, the smaller the seed, the shallower it should be seeded. Drill seeding works for large seeded species, but broadcast seeding is more effective for smaller seeds, which need to be closer to the surface. Seeding too deep is a common cause of seeding failure (Gerling et al. 1996). Seed should be placed at a depth no more than 1½ times their diameter. Nelson et al. (1970) found broadcast seeding produced poor stands of wheatgrasses, but was the most effective seeding method for small seeded "Sherman" big blue grass (*Poa ampla* Merr.).

Many native forb seeds are relatively small and it may be hard to drill seed without placing them too deep. Thus, Pahl and Smreciu (1999) recommend many native forbs be seeded on the soil surface or at a very shallow depth, less than 6 mm. Species with tiny seeds, such as common yarrow and Canada goldenrod should be seeded on the soil surface, while larger seeds such as harebell, blanket flower (*Gaillardia aristata* Pursh), three flowered avens, wild blue flax and prairie coneflower should be seeded on the surface or less than 6 mm deep. Purple prairie clover should be planted about 6 mm deep and wild vetch no more than 10 mm (Pahl and Smreciu 1999). Broadcast seeding is recommended for native forbs to achieve this depth. DePuit and Coenenberg (1979)

found drill seeding to 2.5 cm was beneficial for large seeded species such as western wheatgrass (*Agropyron smithii* Rydb.), slender wheatgrass (*Agropyron trachycaulum* (Link) Malte) and northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.). However, small seeded grasses and shrubs such as sand bluestem (*Andropogon hallii* Hock.), prairie sandreed (*Calamovilfa longifolia* (Hook.) Scribn.), Canada blue grass (*Poa compressa* L.), silver sagebrush (*Artemisia cana* Pursh) and rubber rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Britt.) established better when broadcast. When using a mix of native grasses, forbs and shrubs, broadcast seeding achieved the most diverse stands. Variable seed depth placement achieved by broadcasting onto a moderately rough seedbed ensured at least some seed of each species was at an optimum depth for its germination. Broadcast seeding into roughened soil at twice the drill seeding rate yielded better plant production from native forbs, but had little effect on their canopy cover (DePuit and Coenenberg 1979). At equal seeding rates, drilling slightly improved native forb production, but broadcasting resulted in greater canopy cover from forbs.

Broadcast seeding exposes seeds to light and reduces burial depth, increasing germination of many small seeded forbs. However, it also exposes seeds to numerous risks. Campbell and Swain (1973) found major losses from seed harvest by ants, poor germination and desiccation due to low surface moisture, competition from weeds and moisture stress. Seed harvest ants in Australia preferred lighter seeds to heavy ones (Campbell and Swain 1973). Rodent and bird predation can also result in heavy seed losses on broadcasted plots, where seeds are not covered. Seed losses to these predators can be over 95% (Nelson et al. 1970). Seeds on the soil surface may be exposed to severe drying conditions (Nelson et al. 1970). Seeding rates for broadcast seeding are often higher than those used for drill seeding to counter these losses. Harrowing after seeding, or seeding deeper reduces seed losses, but may also reduce germination.

Since many native forbs have very small seeds, broadcast seeding should result in better overall emergence. Harrowing lightly after seeding should improve seed-soil contact and provide some cover of the seeds. However, care must be taken to prevent burying tiny seeds too deeply.

1.4.2.2 Season of Seeding

Success is generally greater if seeding is done prior to the season of maximum precipitation, when soil moisture will also be at maximum (McGinnies 1960, Munshower 1994, Morgan et al. 1995, Wark et al. 1995). In tallgrass prairie, the best time to seed native species is late spring to early summer (Kilcher 1961, Morgan et al. 1995). Early spring seeding is best on mixed grass prairie (Wark et al. 1995, Pahl and Smreciu 1999). In the mid-western USA, moisture is limited most of the year and late fall seeding is often most effective (Frischknect 1959, Douglas et al. 1960, Kilcher 1961, Munshower 1994, Johnson and Whitwell 1997). Nelson et al. (1970) found plant establishment was better if broadcast seeded in spring than fall in a dry year on semiarid grassland. Cool season (C3) plants grew best during cool, moist weather in early spring or fall, and late fall or early spring seeding worked best (Wark et al. 1995). Spring seeding is better for warm season plants (C4), providing warmer soil temperatures for germination. Harebell, blanket flower, three-flowered avens, wild blue flax and wild vetch are cool season species (Pahl and Smreciu 1999). Common yarrow, purple prairie clover, prairie coneflower and Canada goldenrod are warm season plants. Cool season grasses and some forbs can be seeded in early fall, but legumes seeded after mid August may be more likely to winter kill (Pahl and Smreciu 1999).

Late fall, or dormant fall seeding, just prior to freeze up, may be advantageous for reclamation plantings. Seed is placed as late in fall as possible, and does not germinate until soil warms in spring (Munshower 1994). Late fall seeding may allow more efficient use of equipment and manpower. Cool season plants can be planted in late fall although this is not a common practice (Pahl and Smreciu 1999). Seed losses are higher with late fall seeding (Munshower 1994) due to decay, erosion, desiccation and predation by birds and rodents (Nelson et al. 1970, Campbell and Swain 1973). Seeding rates for late fall are often higher to counter seed losses. Weeds also germinate with or ahead of seeded species in spring, increasing competition. Late fall seeding is sometimes recommended for species with high seed dormancy, since winter conditions may reduce dormancy.

Spring seeding avoids many winter losses (Munshower 1994). Cultivation prior to seeding removes early spring weed flushes, reducing competition for seeded native plants. The biggest disadvantage is predicting precipitation. Scheduling equipment may

also be difficult, since the window of opportunity can be short. Reclamation sites may be too wet to carry equipment until late spring, past the best time for seeding.

Seeding date for native forbs can have a significant influence on successful establishment. Zajicek et al. (1986) found significant interaction between species and seeding date on emergence, stand count, height and winter survival when direct seeding native forbs. Best seeding date varied with species. Salac and Traeger (1982) found native plants responded to spring versus fall seeding. Some forbs germinated best when seeded in spring, indicating they have low dormancy. However, their emergence was reduced when fall seeded. They concluded winter soil conditions damaged seed from these species. A second group of native plants emerged best when seeded in late fall and it appeared low temperatures helped break dormancy. A third group germinated equally well when seeded in spring or fall. These species had no cold temperature dormancy requirement but could survive over winter. November seeding gave better emergence and survival than any other time of year for purple coneflower (*Echinacea angustifolia* DC.) and large flowered beardtongue (*Penstemon grandiflorus* Nutt.). April was best for butterfly milkweed (*Asclepias tuberosa* L.), roundheaded bushclover, purple prairie clover, pitcher sage (*Salvia pitcheri* Nutt.) and yucca (*Yucca glauca* Nutt.). There was no difference between April and November seeding for narrow-leaved sunflower (*Helianthus maximiliani* Schrad.), tall blazing star (*Liatris aspera* Michx.), thickspike gayfeather (*Liatris pycnostachya* Michx.), dotted blazing star and grayheaded prairie coneflower (*Ratibida pinata* (Vent.) Barnh.). October seeding gave poorest emergence and survival for all native forbs; seeding later than April reduced emergence and stand.

Zajicek et al. (1986) found seeding time impacted germination and establishment of native forbs. Greyhead coneflower emerged better when seeded in spring than fall, even though laboratory studies showed it benefited from moist-cold treatment. Purple prairie clover established better when seeded in spring than fall. Johnson and Whitwell (1997) had good establishment of common yarrow from both spring and fall seeding, but found blanket flower and prairie coneflower emerged poorly from both spring and fall seeding. Young et al. (1994) found no difference in establishment of "Appar" blue flax (*Linum perenne* spp. *lewisii*) between spring and fall seeding in a wet year on arid rangeland. In Colorado, Fisher et al. (1987) found wild blue flax and Rocky Mountain

penstemon (*Penstemon strictus* Benth.) established better when seeded in October than spring.

Frischknecht (1951) found season of seeding had little effect on germination and establishment of rangeland grasses, but fall seeded plants appeared to benefit from vernalization (treating seeds to shorten the vegetative period and speed flowering and fruiting). Fall planted grasses were more likely to flower and set seed during the first growing season, while spring seeded grasses were more likely to stay vegetative.

Ideal seeding season depends on site location and climate, forb species and limitations with manpower and equipment. Maximum precipitation in the aspen parkland comes in spring and early summer, so this should be a good time to seed native forbs. Fall seeding may be advantageous for species that germinate better following moist-cold seed treatment. However, other factors such as seed losses and weed competition may reduce any benefits.

1.4.3 Establishment of Native Forbs by Transplanting

Since seed for many native forbs is limited, expensive and difficult to grow, a better option may be to start seedlings in a greenhouse or nursery and then transplant them into the field (Wallace et al. 1986). The greenhouse setting allows controlled conditions during early growth stages; hazards of field germination are avoided and optimal germination and growing conditions are provided (Hartmann et al. 1997). Germination of many native forbs can be improved by seed treatments that can often only be effectively used in a controlled setting such as the greenhouse and are not suitable for field seeding. Greenhouse production allows seeds to be started earlier in the year, extending the growing season (Hartmann et al. 1997). It increases survival rates relative to seeds planted, but at an increased cost (Wallace et al. 1986, Morgan et al. 1995).

Transplant stock may be container-grown, bare-root or wildlings (Munshower 1994). Wildlings are native forbs, grasses, trees or shrubs dug from a native area near where they are to be planted. Bare-root stock, planted dormant without small roots, is commonly used for trees and shrubs. Container-grown forbs, trees and shrubs may be planted while actively growing or when dormant.

Bjugstad and Whitman (1989) transplanted 14 native forbs into spoil piles in

western North Dakota in June. The forbs survived transplanting and grew well through the first year. At the end of summer, transplants were taller than plants grown from seed. Densmore and Holmes (1987) found 73 to 100% survival rates of containerized native seedlings transplanted onto alpine and subalpine sites in Alaska. These plants grew vigorously the first year after planting, even in hot, dry weather. Transplanting container-grown antelope bitterbrush (*Purshia tridentata* (Pursh) DC) reintroduced these shrubs into rangeland, while seeding was generally unsuccessful (Clements and Young 2000). Survival rates of big sagebrush (*Artemisia tridentata* Nutt.) transplanted into gardens in spring were high (Evans and Young 1990); 96% of transplants remained alive at the end of the second growing season and 98% were alive after the third growing season. Water sedge (*Carex aquatilis* Wahl.) seedlings transplanted into high elevation mined peat fen survived best where moisture was available (Cooper and MacDonald 2000). Ninety-five percent of spring planted transplants survived the first growing season, but only 67% were alive the following summer and survival was 50% by the second fall.

Competition from weeds is a concern with transplants (Harkness and Lyons 1997). Below ground competition may be more detrimental to transplants than competition from above ground shoots (Gerry and Wilson 1995). Transplant performance tends to decrease with increasing neighbor mass (Gerry and Wilson 1995).

1.4.3.1 Season of Transplanting

The ideal season for transplanting will depend on location and climate, type of transplant stock used and limitations from manpower and equipment. LeBarron et al. (1938) found tree survival was better with spring than fall transplanting. They attributed this to death losses from frost heaving and lack of opportunity for transplant roots to establish good soil contact, causing plants to suffer moisture stress over winter. They found a significant soil type by planting season interaction. Fall planting was less detrimental on sandy soils than on clays. Marion and Alm (1986) found no difference in survival of container-grown red pine (*Pinus resinosa* Ait.) with spring or fall transplanting in Minnesota. Bare-root stock survived better when planted in spring than fall. However, both container-grown and bare-root stock planted in spring grew more rapidly the first year than those planted in fall. Mullin and Howard (1973) monitored

containerized trees after ten years of growth and found spring transplanting gave better long-term survival and taller trees in red pine and white pine (*Pinus strobus* L.) than fall planting. Season of planting had no effect on white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill) BSP).

1.4.4 Weeds and Weed Control

1.4.4.1 Weeds

Weeds are plants that form populations that are able to readily enter habitats cultivated or otherwise disturbed, usually by human activities (Navas 1991). Some weeds can depress or displace desired plant populations, while others are only competitive in the short term (i.e. one to three years). Weeds form variable populations that evolve under human induced selection pressures.

Vegetation that establishes on a disturbed site is determined by the planted seed mix, the soil seed bank and plant propagules that move onto the site from neighboring ecosystems (Iverson and Wali 1982). Topsoil contains extensive populations of buried weed seeds with seeds of many species long lived in the soil (Roberts and Dawkins 1967), forming a memory of past environmental conditions (Rabinowitz 1981). Species found in the seed bank do not necessarily correspond closely with above ground vegetation (Olmsted and Curtis 1947, Major and Pyott 1966, Thompson and Grime 1979, Rabinowitz 1981, Coffin and Lauenroth 1989). Seed banks contained 6470 seeds m^{-2} on tall grass prairie in Missouri (Rabinowitz 1981). Short and mid-grass prairie contained 721 seeds m^{-2} (Weaver and Mueller 1942). Annual species accounted for the majority of seed bank seeds on short grass prairie in Colorado (Coffin and Lauenroth 1989).

Past management of a site influences the seed bank. Disturbance, through cultivation, industrial activities or grazing increases the number of weed seeds present. Iverson and Wali (1982) found grazed sites had higher seed numbers and a higher proportion of weeds in the seed bank than ungrazed sites. Johnston et al. (1968) found ungrazed Alberta prairie had 2970 seeds m^{-2} while heavily grazed sites had 3240. Lippert and Hopkins (1950) found the seed bank in overgrazed short grass prairie contained 85% weed seeds, while moderately grazed sites contained 58%. In general, cultivated and

grazed sites have the largest seed concentration, with the majority from weedy species (Iverson and Wali 1982).

Annual weeds are often the first plants to appear on a disturbed site (Engler 1954) and may dominate the plant community for the first years after seeding (Gerling et al. 1996). Annual weed seeds spread readily over long distances and make up a significant proportion of the seed bank. They respond to disturbance and bare soil by germinating, emerging and growing rapidly. As a result, annual weeds can have a significant impact on the establishment of desirable native plant species. These weeds may help or hinder growth of native seedlings. They compete with desirable perennial seedlings for light, water and nutrients. However, they also reduce wind speed, soil erosion and provide shelter for perennial seedlings.

Perennial grasses and forbs establish slowly relative to annual weeds (Wark et al. 1995), but there is considerable variation in competitive ability of perennial plants. Seedlings of competition tolerant species will be suppressed initially by annual weed growth. However, perennial seedlings competing with weeds may recover quickly and biomass is often similar to where weeds were controlled the first growing season (Peters 1961, Romo and Eddleman 1987, Aguirre and Johnson 1991, Brothers et al. 1994). By the second growing season plants have usually recovered from competition. Non-aggressive weedy colonizers may improve establishment of native plants (Allen 1990).

Some grasses and forbs, particularly native species, are sensitive to annual weed competition. Many of these species are late successional and slow to germinate, establish and grow. In some cases seedling growth is reduced initially, but perennial plant numbers and productivity may recover in two to three years (Romo and Eddleman 1987, Malik 1991, Masters 1995). Competition from annual weeds during establishment may also lead to revegetation failure (McCarty et al. 1967, Martin et al. 1982).

Competition below ground may be more important than above ground when examining the impact of annual weeds on perennial seedlings (Harris 1977). Plant rooting characteristics are important for competitive ability (Aguirre and Johnson 1991). Annual weeds not only germinate and develop above ground parts more quickly than perennial plants, but also develop root systems faster (Harris 1977). Weeds are able to remove water and nutrients from the upper soil profile, and may exhaust upper profile

moisture supplies to depths beyond the reach of developing perennial plant roots.

Controlling weeds immediately prior to seeding is important to give native seedlings a good start. For a variety of plant species, early emergence gives seeded plants an advantage over competitors in gaining resources (Ross and Harper 1972, Harper 1977, Weaver 1984, O'Donovan et al. 1985).

1.4.4.2 Weed Control

Invasive perennial weeds such as Canada thistle (*Cirsium arvense* (L.) Scop.), quackgrass (*Agropyron repens* (L.) Beauv.), smooth brome grass (*Bromus inermis* Leyss.), crested wheat grass (*Agropyron cristatum* (L.) Gaertn.) and Kentucky blue grass (*Poa pratensis* L.) need to be controlled prior to establishing a native plant community (Morgan et al. 1995, Wark et al. 1995, Gerling et al. 1996). Inadequate weed suppression causes many native grass seed failures (Duebbert et al. 1981). Prior to seeding, perennial weeds should be controlled using tillage, herbicides or a combination of the two. Some perennial weeds will likely escape and continue to be a concern in the seeded plot. Selective application of appropriate herbicides may be needed to control these species for the first few years (Morgan et al. 1995). Once the prairie community matures, perennial weed control will be less important. Presence of native forbs in the plant community may limit opportunities to control weeds since many are susceptible to broadleaf herbicides.

Annual weeds and early successional plants often dominate the first years after seeding (Gerling et al. 1996). However, annual weeds are rarely a problem if managed (Morgan et al. 1995). Non-aggressive weedy colonizers may help establish native plants (Allen 1990). Where no herbicides are possible due to lack of herbicide tolerance in native seedlings, mowing is recommended for annual weed control (Thornburg 1982, Morgan et al. 1995, Wark et al. 1995, Gerling et al. 1996, Pahl and Smreciu 1999). Flail, sickle or rotary mowers should be set to miss native seedlings, but cut weeds before seed set. Excess biomass may be raked or baled. Mowing may have to be repeated every couple of weeks the first years of establishment. Once native species are established and reduce bare soil, annual weeds will decline (Morgan et al. 1995). Hesse and Salac (1972) report mowing wildflowers delayed and extended the blooming period by releasing apical dominance.

Native plants generally grow well in soils with low nitrogen levels, since they evolved with limited soil nitrogen. However, annual weeds require large amounts of nitrogen to prosper. Low soil nitrogen levels should give native species an advantage over annual weeds. Soil impoverishment, adding large amounts of organic material to the soil, which ties up nitrogen as it decays, is sometimes used to give native species an advantage over annual weeds (Wark et al. 1995). Wilson and Gerry (1995) found establishment of native grasses and forbs decreased significantly with increased soil nitrogen levels.

1.5 Issues in Native Plant Community Development

1.5.1 Succession and Plant Community Development

Reclamation and revegetation are human activities used to start, enhance or bypass succession in restoring plant communities following human disturbance. Reclamation is the process of converting disturbed land to productive land, while revegetation is the process of replacing plant communities. Both processes can be designed to lead to various end points in plant community development. Where the desired plant community is an annual crop, reclamation and revegetation can usually create a reasonable similar soil and plant community within a couple of years. Where the desired plant community is a native plant community similar or identical to adjacent undisturbed native communities, reclamation and revegetation processes typically try to start succession by rebuilding soil and introducing appropriate plant species. Hopefully successional processes will eventually rebuild the desired plant community over a number of years.

Succession can be defined as the change in species composition and community structure over time (Pickett 1976). Succession is the process by which a plant community responds to a disturbance or changes over time. Primary succession occurs on virginal substrate, with no remnants of earlier vegetation (van der Maarel 1988). Secondary succession is the re-establishment of a reasonable facsimile of the original plant community after a disturbance (Horn 1974), and assumes the presence of developed soil organic material on the site (van der Maarel 1988).

The classical view of ecological succession is that following a disturbance, several plant species assemblages sequentially occupy the site (Clements 1916, 1920, Weaver and Clements 1938, Dyksterhuis 1946). Pioneer species move in initially when competition for light and nutrients is low. These species are unable to reproduce with competition, so are gradually replaced. Eventually species that can replace themselves indefinitely will dominate the site. The community gradually resumes the structure and composition of the surrounding undisturbed area. Each group of species modifies site conditions so that they become less able to persist, but the site becomes more suitable for their successors (Clements 1916). The final, more or less stable, end point of succession is the climax plant community.

Later researchers felt Clementsian climax vegetation theory could not fully describe plant community succession in many areas (Pickett 1976, Peet and Christensen 1980). Researchers began trying to describe mechanisms facilitating plant community development. Plant life history traits became a major focus in succession theories. Engler (1954) proposed secondary succession generally resulted from differences in plant life span. Margalef (1963) thought succession occurred because plants that could use energy more efficiently eventually dominated the site. Drury and Nisbet (1973) thought succession could be understood as consequences of plant species' colonizing ability, growth and survival relative to the environment. Pickett (1976) thought succession resulted as vegetation communities responded to changes in stress gradients on a site over time. Life history of a plant species determined where it fit into the successional process.

Connell and Slatyer (1977) proposed three mechanisms for succession. Facilitation was basically the Clementsian model, also called relay floristics by Engler (1954). In this mechanism early successional species modify the environment and facilitate establishment of later successional species. The inhibition mechanism, which built on Engler's (1954) initial floristic composition, occurred where initial invading species could regulate succession so later successional species were unable to grow or invade the site in the presence of healthy, undamaged early successional species (Connell and Slatyer 1977). The tolerance mechanism occurred where floristic changes in a community were the result of different life history traits and differential ability of late successional species to tolerate initial environmental conditions. Noble and Slatyer

(1980) believed vital attributes of a plant species determined its role in succession. Shifts in species composition may not reflect progressive entry of later successional plants into the community, but instead be the gradual emergence and eventual dominance of species that were present but inconspicuous since the disturbance. Their critical vital attributes were method of arrival or persistence at the site, ability to establish and grow to maturity in the community and time for the plant to reach critical life stages.

More recently, several researchers described general models of succession. Tilman (1985) proposed the resource-ratio hypothesis as a general theory. The resource-ratio hypothesis presumes plant species are specialized to grow best with different proportions of limiting resources. Composition of the plant community changes when relative abundance of limiting resources changes. Tilman proposed that nitrogen levels and light were often the main limiting resources for plants. Each plant species is a superior competitor for a particular ratio of soil nitrogen to light. As soil and light levels change over time, plant species change accordingly, favoring species most competitive at that particular ratio. This theory is based on plant life history traits, but assumes nitrogen to light ratio is the gradient along which plant life histories have evolved.

Pickett et al. (1987) proposed a hierarchical structure that assessed causes of succession (open sites, species being differentially available and competitive ability), interactions, processes or ecological events causing succession and site specific factors in succession. Huston and Smith (1987) observed an inverse correlation between traits that make a species successful in early stages and those that ensure success in late succession. They believed plant species could be placed onto a continuum of plant strategies based on these traits. Species replacement during succession resulted from competition between individual plants rather than populations. Their model proposed that inverse correlation of life history and physiological traits conferring competitive ability under different environmental conditions would produce successional patterns like those observed in the field when applied at an individual plant rather than population level. Successional processes are critical to revegetation success in native plant communities. Decisions on seeding, species selection and weed control are based on current understandings of plant community development.

1.5.2 Plant Community Biodiversity

Biological diversity, or biodiversity, is the variety of life and its processes in an area (West 1993). It includes the number and proportions of individual organisms present, genetic differences between and within these organisms and the communities, ecosystems and landscapes in which they appear. It also includes interactions among all of these things.

Public concerns about maintaining biodiversity, particularly on publicly owned lands, are growing and pressuring government to manage lands to enhance biodiversity. Biodiversity is important for a number of reasons (West 1993). Many people feel a moral obligation to protect other living organisms even if they are not presently of economic value. Maintenance of biodiversity is also important for aesthetic reasons. People value opportunities to see and appreciate nature, whether in parks or along roadsides. In addition to economic returns from the aesthetic appeal of natural areas, these areas provide direct economic returns by providing food, fuel, building materials and medicine. All agricultural species originally came from natural populations. Diverse natural areas may hold genetic material needed for adaptation of existing agricultural species, as well as new species adapted to changing world environmental and economic conditions. Maintenance of biodiversity helps ensure genetic resources are available for future needs. Finally, diverse ecosystems provide essential services, including maintenance of the atmosphere, soil genesis, fertility and soil nutrient cycling. Increasing plant biodiversity may give greater ecosystem productivity (Naeem et al. 1994, Tilman et al. 1996). In native plant revegetation projects, decisions about seed mix (e.g. how many species to include) can impact both short and long term diversity of plant species on the site. Increasing diversity of desired plants on these sites in the first couple of years after establishment generally requires use of a diverse seed mix. However, research on long term effectiveness of this strategy and alternative strategies is only just beginning.

An ongoing debate about the functional consequences of species biodiversity at the ecosystem level is found in the scientific literature. The diversity-stability hypothesis proposes species have different traits, so diverse ecosystems are more likely to contain some species that can thrive during environmental perturbations (McNaughton 1977, 1985, West 1993, Tilman and Downing 1994). This hypothesis is similar to the rivet

hypothesis of Ehrlich and Ehrlich (1981), who suggest each species plays an incrementally important role in a community, similar to rivets in an airplane. Some species can be lost, but the loss of too many will critically weaken the system. Many researchers found increasing diversity improves ecosystems (Naeem et al. 1994, 1996, Tilman et al. 1996, Tilman 1996). Tilman and Downing (1994) found increased species richness gave Minnesota grasslands greater drought resistance. Sites with more plant species maintained higher productivity during drought and recovered more quickly after drought. Ecosystem resistance to drought was an increasing but non-linear function of species richness. When the plant community was diverse, more species were functionally similar. Hector et al. (1999) found that a loss of plant diversity on European grasslands led to reduced productivity, with each halving of diversity leading to a 10 to 20% reduction in productivity. These theories suggest establishment of more species is better than fewer species.

The species-redundancy hypothesis states many species in a community are so similar that ecosystem function is independent of diversity, as long as major functional groups are present (Tilman and Downing 1994). A community is composed of a few functional groups, each containing several ecologically equivalent species (Walker 1992). Some of these equivalent species can be lost without impact on ecosystem function. MacGillivray and Grime (1995) found biological characteristics of dominant plants rather than number of plants controlled ecosystem productivity. Tilman et al. (1997) reported functional rather than species diversity had a greater impact on ecosystem processes.

Several researchers found species composition and traits of dominant species are more important than diversity (Hooper and Vitousek 1997, Jollife 1997, Tilman et al. 1997, Wardle et al. 1997, Grime 1998, Hooper 1998). They found the number of functionally different roles in the community was a stronger determinant of ecosystem processes than number of species present. Hooper and Vitousek (1997) found that with California grassland plants, the variety of functional groups of plants present had a larger effect on ecosystem processes such as yield and nutrient use than species richness. However, at some point further loss of key species can impair ecosystem functioning, so number of species present cannot be completely ignored (MacGillivray and Grime 1995, Tilman et al. 1997). The presence of keystone species, species whose direct or indirect

effects on the survival of other species or ecosystem function is disproportionately large in relation to their abundance, is critical to ecosystem functioning (Westman 1990). These keystone species have not been fully identified in many ecosystems (Grime 1997). These theories suggest that native plant revegetation projects should concentrate on establishing species from critical functional groups (e.g. bunch grasses, rhizomatous grasses and legumes) rather than all possible plant species.

Many revegetation practices attempt to enhance biodiversity. In semiarid and arid regions natural plant invasion of disturbances occurs slowly (Munshower 1994). Once a grass cover is established by reseeding on a disturbance, the site tends to resist invasion by new species. One commonly used way to increase diversity is to plant seed mixes containing numerous grass, forb and shrub species. This practice has been somewhat successful in establishing diverse plant populations on some sites, but has not been universally successful.

1.5.3 Genetic Diversity in Native Species

Genetic variation exists in a plant species, both within and between populations. This genetic variation allows the species to adapt and evolve when environmental conditions change. A species may be made up of a number of ecotypes, a population of plants that is genetically differentiated in response to the conditions of a particular habitat (Tureson 1922). Ecotypes reflect elevation, precipitation, temperature, growing season, soil and site characteristics where the population is found. Each population is unique, since it consists of a genome shaped by the interaction of biological and physical features of the environment. The total genetic variation in a species can be organized into a hierarchy including variations among plants in physiographic regions, among populations of plants within regions, among families within populations and among siblings within families (Millar and Libby 1989, Munda and Smith 1995).

Genetic variability varies with species. Plant life history has a large impact on genetic variation. Early successional or weedy species with widespread distributions have low genetic variability within and between populations (Hamrick et al. 1979, Linhart 1995). These species are adapted to highly disturbed conditions that vary little among sites. A few general-purpose genotypes can adapt to typical growing conditions.

Endemic species generally have small populations, less gene flow between populations and often grow in homogeneous environments. They have less genetic variation in the population. Generally, non-weedy species with broad distributions have high levels of genetic variability between and within populations. They experience a wider variety of ecological conditions within and between populations and have a higher potential for gene flow. Long-lived woody perennials have the most genetic variability. In many conifers, the majority of genetic variation is found within, not between, populations (Linhart and Davis 1991).

In general, plants that are outbreeding, have widely dispersed pollen or seeds and are long-lived have high levels of genetic variation among individuals within populations and less variation between populations (Hamrick et al. 1979, Linhart 1995). Plants that are inbreeding, use asexual or mixed reproductive systems, disperse seed and pollen over short distances, have small, disjunct populations, are annuals or short-lived have little genetic variation within populations, but wide variation between populations.

Agronomic or tame plant species have been selected and bred to be adapted to a particular set of environmental conditions. These species have little genetic variation. Native plant species have evolved in specific environmental conditions. When selecting seed for native species, it is important to consider ecotypes and how they may be adapted to the revegetation site (Millar and Libby 1989). Several problems may occur if plants are not adapted to growing conditions at the site. One consequence, which may not be the worst situation for the surrounding native community, is that introduced native stock may die soon after planting. Thornburg and Fuchs (1978) report that plants moved too far north of their area of adaptation grow later into the growing season. These plants often fail to set viable seed before frost and may winterkill. Introduced native stock may also suffer from eventual death (Millar and Libby 1989). Plants moved too far south of their area of adaptation fail to use the full growing season, are less vigorous and more susceptible to disease. They may survive a few years, but gradually grow weaker and eventually die (Thornburg and Fuchs 1978). Introduced plants may survive on site, but grow more poorly than stock from locally adapted populations. Finally, introduced plants may survive and do well on site, but may degrade the genetic diversity of plants in nearby undisturbed areas (Millar and Libby 1989). Inbreeding can be a concern if the introduced

stock is derived from a few closely related parents. The next generation of inbred offspring is less vigorous and healthy than the parents. This is of particular concern in restoration projects, where limited seed is available for some species and few native stands are left. Introduced or non-local plants can also interbreed with native stock surrounding the revegetation site, and may pass on non-adapted genes or gene complexes to the offspring of the native stock (Millar and Libby 1989, Linhart 1995). The progeny may be more poorly adapted to the environment than either parent.

Selection of native plant ecotypes adapted to a revegetation site may be difficult. Recommendations for selecting ecotypes are based on collection radius guidelines (Thornburg 1982, Romo and Lawrence 1990, Munshower 1994, Wark et al. 1995, Gerling et al. 1996). These recommendations are based on Cooper (1957), who suggested ecotypes of native plants could be moved 400 to 500 km north or 150 to 250 km south of the point of origin to areas of similar soils and climates and give satisfactory performance. However, this recommendation was based on anecdotal rather than empirical experience.

Several researchers suggest that selection of adapted ecotypes would be easier if seed zones were established for native grasses and herbaceous species (Millar and Libby 1989, Rehfeldt 1991). These seed zones would be similar to those used by the United States Forest Service for collection and replanting of conifer seed and seedlings (Millar and Libby 1989, Knapp and Rice 1994). However, little research has been done on genetic diversity in herbaceous native species, so research would need to be expanded before seed zones could be used (Rehfeldt 1991, West 1993).

Another option for selecting native ecotypes adapted to a revegetation site would be to develop collections of seed for native species that included as wide a range of adaptability as possible (Munda and Smith 1995). This seed collection would ideally contain plants adapted to all typical native environments where the species could be found. Plants genetically adapted to most sites would be in the seed mix. The widely adapted seed collection would be useful for large disturbances and areas where localized seed collection was difficult.

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CHAPTER 2 SEEDED NATIVE FORB ESTABLISHMENT ON DISTURBED ASPEN PARKLAND

2.1 INTRODUCTION

Interest in using native plant species to reclaim industrial disturbances is increasing. Native grasses are commonly used for reclamation and research has shown many can be established relatively easily (Sorenson and Holden 1974). However, reclamation success may be improved by using a mix of species, including plants with different phenological traits and life histories (Brown and Chambers 1989). Although forbs are an important component of native plant communities (Cook 1983), they are seldom used in reclamation. Seed supply is limited, seed is expensive, germination rates are often low and little information is available on establishment on industrial sites (Blake 1935, Sorensen and Holden 1974, Voight 1977, Bjugstad and Whitman 1989).

Forbs add diversity to the plant community (Bjugstad and Whitman 1989, Gerling et al. 1996), enhance ecosystem structure and provide niches for other life forms. Many native forbs are pioneer species and help rehabilitate disturbed sites by preventing soil erosion and improving nutrient cycling (Salac and Hesse 1975, Zajicek et al. 1986, Bjugstad and Whitman 1989). Forbs add aesthetic appeal to a reclaimed landscape and help blend the disturbed site and surrounding vegetation. Most reclamation seed mixes include at least one agronomic legume to fix nitrogen (Munshower 1994), with the assumption that they will be displaced gradually from the native plant community (Munshower 1994). Native legumes, which are constituents of the surrounding plant community, may be a better choice.

When used on reclaimed sites, native forbs are commonly seeded at the same time as grasses (Salac and Hesse 1975, Zajicek et al. 1986). However, they are generally considered hard to establish from seed due to improper seeding techniques, insufficient seeding rates, poor seed quality and germination, inability of seedlings to compete with grasses and improper management (Zajicek et al. 1986).

Most native forbs have small seeds and seeding depth recommendations, based on seed size, are surface to less than 6 mm (Pahl and Smreciu 1999). Thus broadcast versus drill seeding is often recommended. Broadcast seeding into roughened soil at twice the drilling seeding rate improved native forb production but had little effect on canopy cover

(DePuit and Coenenberg 1979). At equal seeding rates, drill versus broadcast seeding improved native forb production, but broadcast seeding increased canopy cover. DePuit and Coenenberg (1979) found broadcast seeding increased plant species diversity, since at least some seed of each species was likely placed at an optimum depth for germination. Drill seeding favored large over small seeded species. Broadcast seeding exposes seeds to light and reduces burial depth, increasing germination of many small seeded species. However, it also exposes seeds to a number of risks. Campbell and Swain (1973) found major losses with broadcast seeding from harvest by ants, and poor germination and desiccation of the radicle tip due to low surface moisture levels and competition from weeds. Rodent and bird predation resulted in seed losses over 95% when broadcast seeds were not covered (Nelson et al. 1970).

Field germination, emergence and survival are low for many native forbs (Currah et al. 1983, Wallace et al. 1986, Bjugstad and Whitman 1989). Bjugstad and Whitman (1989) found many species, including purple prairie clover (*Petalostemon purpureum* (Vent.) Rydb.), wild blue flax (*Linum lewisii* Pursh), velvety goldenrod (*Solidago mollis* Bartl.) and prairie coneflower (*Ratibida columnifera* (Nutt.) Wooton & Standl.) required up to 120 days for emergence. However, Blake (1935) found seed for half the native forbs studied germinated within two weeks, while the other half germinated within two to four weeks. Germination requirements of native forb species vary. Sorensen and Holden (1974) found that of 23 South Dakota native forbs studied, 70% germinated under normal field conditions, 22% needed moist-cold seed treatment, one species needed scarification and one species did not germinate.

Native forb seedlings grow slowly (Blake 1935) and face increasing competition from grasses and weeds when they emerge. Howell and Kline (1994) found competition from weeds and grasses reduced seed germination and establishment success of purple prairie clover. Weeds had a greater impact than did grasses. Growing conditions at the time of forb germination and the first month after germination were critical to seedling survival and growth (Goldberg and Werner 1983). Litter reduced emergence of Canada (*Solidago canadensis* L.) and sharp-toothed goldenrod (*Solidago juncea* Ait.) (Goldberg and Werner 1983). Reduced emergence was attributed to low light availability, although impedance to seedling growth from litter, fungal infections encouraged by dark, moist

conditions and chemical inhibitions could also have contributed. Many native forbs that develop readily into good stands reproduce vegetatively as well as by seed (Salac and Traeger 1982), a desirable characteristic for survival in a highly competitive plant community.

Seeding date influenced native forb establishment. Zajicek et al. (1986) found significant species by seeding date interactions for emergence, stand count, height and winter survival. Salac and Traeger (1982) found November seeding resulted in better emergence and stand survival for some species, April seeding was best for others and some species were unaffected by seeding date.

Annual weeds are often the first plants to appear on a disturbed site (Engler 1954) and frequently dominate the plant community the first years after seeding (Gerling et al. 1996). They may have a significant impact on establishment of desirable native species. Weeds compete with native seedlings for light, water and nutrients. However, they also reduce wind speed, soil erosion and provide shelter for seedlings. Seedlings of competition-tolerant species may be initially suppressed by annual weed growth, but biomass production can recover quickly, and is often similar to where weeds were controlled the first growing season (Peters 1961, Romo and Eddleman 1987, Aguirre and Johnson 1991, Brothers et al. 1994). Non-aggressive weedy colonizers may help establishment of native plants (Allen 1990). By the second growing season after establishment, plant productivity usually recovered from competition. However, invasive perennial weeds, such as Canada thistle (*Cirsium arvense* (L.) Scop.), quackgrass (*Agropyron repens* (L.) Beauv.) and smooth brome grass (*Bromis inermis* Leyss.) need to be controlled prior to establishment of a native plant community (Morgan et al. 1995, Wark et al. 1995, Gerling et al. 1996). Inadequate weed suppression results in more native grass seed failures than anything else (Duebbert et al. 1981).

Establishment of native forbs on tall grass prairie has been studied in detail (Blake 1935, Greene and Curtis 1950, Salac and Traeger 1982 and Zajicek et al. 1986) and a few researchers studied use of native forbs in the midwestern United States (Bjugstad and Whitman 1989, Tyser et al. 1998). However, research on establishing native forbs on reclamation sites in Alberta is limited. This project examined the establishment of several forb species native to Alberta aspen parkland on disturbed sites. Most of the

Aspen Parkland Ecoregion is currently used for agricultural production. Less than 5% of the area remains as natural habitat (Morgan et al. 1995) and is threatened by invasion of introduced plant species and increased disturbances, making research into reestablishing these native plant communities critical.

2.2 Research Objectives

The objectives of this research were:

1. To assess survival and reproductive potential of selected seeded native forbs in three locations in the aspen parkland.
2. To compare survival and reproductive potential of selected native forbs seeded in spring and fall.
3. To compare survival and reproductive potential of selected seeded native forbs growing with weed competition to those mowed to control annual weeds.
4. To identify native forbs that invade disturbed sites from the seed bank and surrounding vegetation.

2.3 Research Site Description

Research sites were located at the University of Alberta Ellerslie Research Station (53° 27' 1" N, 113 ° 37' 56" W) on the south edge of Edmonton, Alberta and adjacent to Oster Lake (53 ° 37' 30" N, 112 ° 55' 10" W) and Tawayik Lake (53 ° 36' 37" N, 112 ° 53' 41" W) in Elk Island National Park, 37 km east of Edmonton.

The Ellerslie Research Station is located in the Aspen Parkland Ecoregion (Strong and Leggat 1992). This area is the climatic and ecological transition zone between the boreal forest and grassland areas and covers about 8% of Alberta. A mixture of Black and Dark Gray Chernozemic soils and native grassland and deciduous forest communities form a parkland. The grassland community historically was dominated by rough fescue (*Festuca scabrella* Torr), bluebunch fescue (*Festuca idahoensis* Elmer), June grass (*Koeleria macrantha* (Ledeb.) J.A. Schultes f.) and needle grasses (*Stipa* spp.). Trembling aspen (*Populus tremuloides* Michx.), saskatoon (*Amelanchier alnifolia* Nutt.)

and willows (*Salix* spp.) form the major tree component of the community. The research site is located in the prairie-boreal climatic region (Strong and Leggat, 1992). Average summer temperature for this climatic region is 14.4 °C, ranging from 7.7 to 20.9 °C. Average winter temperature is -8.7 °C, ranging from -14 to -3.7 °C. Mean annual temperature is 3.3 °C. Total annual precipitation averages 412 mm, with 259 mm falling in summer. The research site has been used for agricultural research for ten years, using a crop fallow rotation (Appendix A).

Elk Island National Park is located in the Beaver Hill Upland, in the Low Boreal Mixedwood Ecoregion and the boreal climatic region (Strong and Leggat 1992). Average summer temperature for this climatic region is 13.8 °C, ranging from 7.0 to 20.4 °C. Average winter temperature is -10.5 °C, ranging from -15.8 to -5.3 °C. Mean annual temperature is 0.8 °C. Total annual precipitation is 380 mm, with 235 mm falling in summer. The Oster Lake area is dominated by trembling aspen with balsam poplar (*Populus balsamifera* L.) on wetter sites (Crown 1977). The area has a dense shrub layer. The Tawayik Lake area is more open with areas of grassland mixed with aspen stands (Crown 1977). The research sites were located in areas that were overgrazed and contained a high proportion of invader species (Bush 1998) (Appendix A).

2.1 Materials and Methods

2.1.1 Experimental Design and Treatments

The experimental design was a complete randomized split block with replications. Four blocks were located at the Ellerslie Research Station, and two blocks each at Oster Lake and Tawayik Lake in Elk Island National Park. Each block was 8.8 m long and 12.6 m wide with 1 m borders on all sides. Main treatment compared season of seeding, with half seeded in spring and half seeded in fall. Within each block, half of each fall and spring seeded plot was randomly assigned to either a mowed (to control annual weeds and open the canopy) or an unmowed treatment.

Sites were drill seeded to a mix of six native grasses (Table 2.1). Ten native forb species commonly found in undistrubed aspen parkland ecosystems, for which seed was available, were broadcast seeded immediately following grass seeding. The seed mix

consisted of 70% grasses and 30% forbs by weight, with each species having equal amounts of pure live seed (PLS) to give theoretically equal numbers of plants from each species. The 70:30 ratio of grasses to forbs represented percent cover and species number in Aspen Parkland (Gerling et al. 1996).

Fall treatments were seeded with native grasses on October 4 and 5 and with forbs on October 11 and 12, 1997. Spring treatments were seeded with native grasses on May 24 and with forbs on May 25, 1998. Fall establishment dates were late enough that seeds would not germinate until spring, but before snow and frost prevented seeding. Spring seeding dates were selected to optimize soil moisture, rainfall potential and soil temperatures for germination and establishment.

The mowed plots were cut to a height of 10 to 15 cm twice during the first growing season. Mowing was timed to prevent the majority of weeds from setting seed. Treatments were mowed June 21 and August 5, 1998 with a tractor-drawn, six-foot flail mower. The plots were not mowed in 1999 because annual weed growth was much reduced.

2.1.2 Site Establishment

In August 1997, sites were rototilled to a depth of 15 cm. Plant regrowth was sprayed with 3 L ha^{-1} of glyphosate (Roundup) in late August. Sites were rototilled again in early September and regrowth sprayed with glyphosate on September 29, 1997. On May 24, 1998, immediately prior to seeding, spring seeded treatments were rototilled to the same depth. No fertilizer was added, although the Ellerslie site had been fertilized in the past (Appendix A). A 10 m wide strip around the site at Ellerslie was cultivated several times in summers 1998 and 1999 as required by research station policy. Plot borders at Ellerslie were mowed in 1998 to facilitate access. No plot border cultivation was done at Oster and Tawayik Lakes, but the area within the fence not used for research was mowed in summer 1998.

A seeding rate of 200 PLS m^{-2} was used, with a forb seeding rate of 60 PLS m^{-2} (Table 2.1). This was equivalent to a seeding rate of 524 g m^{-2}, with forbs seeded at 177 g m^{-2}. This rate is lower than recommended for native species (Munshower 1994, Wark et al. 1995) to enhance invasion from native species in the surrounding plant

communities. Grasses were seeded using an eight-cone drill seeder, while forbs were broadcast using a handheld spreader. Commercial poultry starter was used as a carrier for both operations. Fall seeded plots were not harrowed after seeding due to wet soil conditions. To ensure consistency, spring seeded plots also were not harrowed.

The seeding rate calculation was based on PLS, seeds per kilogram and purity and germination for each species. Purity and germination were obtained from seed certificates or seed analyses from a seed laboratory (20/20 Seed Labs. Ltd. 1997). Seed weight was determined by twice counting and weighing 300 seeds of each species with chaff and other non-seed matter included then converted to number of seeds per kilogram. Details on native grass seeding rates and seeding method are given in Pitchford (2000). The same seed lots were used for both fall and spring seeded treatments. Seeds for spring treatments were stored in a freezer from November 1997 until May 1998. Freezing the seeds was not intended to imitate cold stratification as experienced by seeds in the ground over winter.

Canada thistle invaded Ellerslie in 1998. Since thistle can be very competitive, each plant was periodically hand spot sprayed with a 1:50 concentration of glyphosate through the 1998 and 1999 growing seasons. Research plots at Ellerslie were located with other field crop research plots and grazing from large herbivores was not a problem. Sites at Elk Island National Park were fenced to prevent grazing by large herbivores.

2.1.3 Field Sampling and Assessment

2.1.3.1 Soils

Random soil cores were taken from the borders between plots at eight locations per block on May 15, 1998. Cores were taken at 1 to 5, 5 to 15, 15 to 30, 30 to 45 and 45 to 60 cm increments. The eight samples for each increment in each block were bulked to give one sample per block for each of the five depths (40 samples). Samples were air dried prior to analyses. Samples were analyzed for exchangeable nitrate and ammonium nitrogen using a 5:1 potassium chloride extract (2M), pH, electrical conductivity and organic carbon by Walkley-Black (Carter 1993). Sand, silt and clay were determined by hydrometer (McKeague 1978). Acetate fluoride, ammonium acetate and 0.001 M

calcium chloride extractions were used to determine phosphate phosphorus, potassium and sulfate-sulfur levels, respectively (McKeague 1978). Soil penetration resistance was measured using a CN-973 Soil Test proving ring cone penetrometer after planting in May 1998. Ten readings were taken in each block, at 2.5, 5, 7.5, 10 and 15 cm depths.

2.1.3.2 Vegetation

Seeded forbs were counted in September 1998 and 1999. Each plot was divided into 1 by 8 m sections to improve accuracy and ease of finding forbs. Each forb was identified and described according to presence or absence of flowers and seeds, growth form and position in the mowed or unmowed portion of the plot. In the second growing season, height of the first three plants of each species found and every third or fifth plant afterwards, depending on the anticipated abundance of the species, was determined by measuring the shoot from the base to the apex of the tallest stem.

The soil seed bank was assessed for invading species by identifying species growing in the unseeded borders around the plots and species in the plots that had not been included in the seed mix. Monitoring was done at three to four week intervals from May 15 to September 30 in 1998 and 1999. A reconnaissance vegetation survey was done in June and August 1998. Species off-site were identified because they could contribute seed or vegetative propagules to the sites. The area was surveyed by walking the perimeter of each block, to a distance of 10 meters from the corner of the blocks, and identifying plant species present.

Plots for research on transplanting forbs (Chapter 3), in the same sites and with identical management, were assessed in 1998 for native forb seedlings in the same manner as seeded plots. Native forbs were recorded, but no other measurements taken. Transplanted forbs were excluded from this assessment. Comparison of forb species found and numbers present allowed assessment of which native forb species invaded without human assistance, since no forbs were seeded on transplant sites. Forbs on these plots were not assessed in 1999, since transplanted forbs had produced seed.

2.1.3.3 Climate

Meteorological stations located at the Edmonton International Airport, 5 km south of the Ellerslie site and the Elk Island National Park warden station, approximately 10 km from the Oster Lake and Tawayik Lake sites, were used to record average monthly temperatures and total monthly precipitation. Climate data were obtained from Environment Canada.

2.1.3.4 Statistical Analyses

Data were analyzed with the General Linear Model (GLM) of SAS (SAS 1990). When examining means of all seeded forbs, the model used a split plot design to test effects of location, season of seeding, mowing and their interactions. Time was used as a repeated measure. Dependent variables included number of live forbs, percent of forbs that bloomed, percent of forbs that set seed and height of forbs. Individual forb species results were investigated using the same design and dependent variables. Throughout, the Pdiff test was used for means separation in comparisons between the three locations and interactions with location. For this research, a probability of $P \leq 0.10$ was defined as significant. This research was exploratory in nature and a higher than normal significance level was chosen to indicate trends. Exact probabilities for GLM tests are presented in the tables. For some plant species, where no plants grew on some treatments, analyses of plant characteristics (i.e. flowering, seed set and height) were done comparing main effects only, without interactions.

2.2 Results and Discussion

2.2.1 Climate

Average May through September (summer) temperatures at both Ellerslie and Elk Island were warmer than the 30 year average in 1997 (14.4 °C vs. 16.7 °C) and 1998 (14.7 °C vs. 16 °C) (Appendix A). In 1999, summer temperatures were cooler than the 30 year average, 12.4 °C at Ellerslie and 13.1 °C at Elk Island.

Total annual precipitation at Elk Island in the year prior to and two years

following seeding (1997 to 1999) was below the 30 year average, and ranged from 494 mm in 1997 to 365 mm in 1999 (Appendix A). Total annual precipitation at Ellerslie over the same time period was generally higher than the 30 year average, ranging from 524 mm in 1997 to 434 mm in 1998. Sites at Elk Island received slightly more precipitation prior to fall planting in 1997 than those at Ellerslie. Both areas received similar amounts of precipitation over winter 1997. Ellerslie received more precipitation (418 mm) from April to September 1998 than did Elk Island. However, Ellerslie received less rain in spring and early summer than did Elk Island, more precipitation in winter 1998/1999 (140 mm vs. 99 mm), and more precipitation in summer 1999 (333 mm vs. 267 mm). Seeds germinating and growing at Elk Island sites from both the fall and spring plantings may have had slightly better moisture conditions for establishment than those at Ellerslie, but neither area was drought stressed during these years.

2.2.2 Soils

Soils at the three locations varied (Appendix A), although none presented serious limitations to plant growth. Soil at Tawayik Lake was predominately Uncas Loam, an Orthic Dark Gray Chernozem. Soil pH in surface horizons was slightly acidic (6.0 to 6.4) and became increasingly basic below. Soil at Oster Lake was predominately Cooking Lake Loam, an Orthic Gray Luvisol. Soil texture tended to be siltier, while texture at Tawayik Lake was sandier. Soil pH at Oster Lake was moderately acidic, ranging from 5.8 at the surface to 5.5 below. Soil at Ellerslie was Malmo Silty Clay Loam, an Eluviated Black Chernozem. Surface and subsoil pH were neutral, ranging from 6.7 to 6.8.

Soil density in the top 5 cm was low for all sites (0.3 Mpa) since the sites had been rototilled prior to sampling (Appendix A). Soil density remained low to 15 cm of depth at Ellerslie (0.7 Mpa), but increased significantly below 5 cm at both Tawayik Lake (2.3 Mpa) and Oster Lake (2.1 Mpa). This may have restricted rooting depth of plants seeded at these two locations.

Surface soil salts at all three locations could present slight limitations to plant growth. Salt levels were lowest at Oster Lake and highest at Ellerslie (Appendix A). Very high organic carbon levels were present at the soil surface at Tawayik Lake (6.9%),

but levels dropped sharply below 5 cm. High organic carbon levels were present in surface soils at Oster Lake (3.2%) and levels gradually decreased to very low (1.2%) with depth. Ellerslie soil had high organic carbon levels throughout the upper profiles, ranging from 5% at the surface to 4% at 45 to 60 cm.

Soil nutrient levels varied considerably with location (Appendix A). Nitrogen, phosphorus and potassium levels were very high in the top 5 cm at Tawayik Lake, but dropped rapidly to fairly low levels below this depth. At Oster Lake, surface soil had high levels of nitrogen and phosphorus, and levels of these nutrients tended to stay high in the top 60 cm. Oster Lake had lower amounts of potassium and low levels of sulfur throughout the depths sampled. These sites had been disturbed two years prior to establishment of these plots and had been fallow for this time, allowing increased mineralization. Soil at Ellerslie had the lowest levels of soil nitrogen and phosphorus, but had higher levels of potassium and sulfur. Other researchers have found the number of native seedlings that establish decreases significantly as soil nitrogen levels increase (Biondini and Redente 1986, Wilson and Tilman 1991, Wilson and Gerry 1995).

2.2.3 Seed Bank and Invader Species

Many seed bank species were native or introduced weedy annuals (Appendix B). Lambsquarters (*Chenopodium album* L.) and maple-leaved goosefoot (*Chenopodium gigantospermum* Aellen) and other annuals were high at Oster and Tawayik Lakes. The most common annual at Ellerslie was canola (*Brassica campestris* L.). Canada thistle was the major perennial weed at Ellerslie and was present at Oster and Tawayik Lakes in small amounts. Perennial invaders were greatest at Tawayik Lake, with most cover from dandelions (*Taraxacum officinale* Weber), alsike clover (*Trifolium hybridum* L.) and red clover (*Trifolium pratense* L.). Perennial weeds were insignificant at Oster Lake until the second growing season when alsike and red clover increased on some plots.

Oster and Tawayik Lake sites were closely surrounded by native vegetation and had been disturbed only two years prior to seeding. Invasion from desirable native species was greater at these sites, with common yarrow (*Achillea millefolium* L.) and wild vetch (*Vicia americana* Muhl.) observed in high numbers (Appendix B). Ellerslie is a farmed research area, under cultivation for a number of years. Low invasion from

desirable native forbs was expected, but a large number were found, with common yarrow and wild vetch most common.

The native seed lots used on these plots contained small amounts of seed from other plant species (Appendix B). Thus some species could have been introduced through the seed. Any of these species that established on the sites were identified in the seed bank survey.

2.2.4 Native Forb Establishment

All 10 seeded native forbs established, although some were present in very low numbers (Table 2.2). The percent of PLS planted that produced a live plant after the first and second growing seasons was also low for most species (Table 2.2). Common yarrow established best, averaging 7% in both growing seasons, followed by wild vetch, which averaged 6% the first year and 12% the second year. Other species had low rates of establishment, with less than 5% PLS producing a live plant.

Tyser et al. (1998) also found low correlation between seeding rate of native forbs and establishment. They seeded 300 forb seeds m^{-2} in a native grass/forb mix and concluded this rate may be too low for detectable results. The forb seeding rate of 60 PLS m^{-2} in this research produced an average 1.6 plants m^{-2}. Seeded native plant communities develop slowly and this level of forb establishment in a mixed plant community early in succession may be adequate. Many forb species seeded are early successional, spread by rhizomes and will expand over time.

Comparing seeded forbs on seeded and unseeded (transplant) plots showed seeding significantly increased native forb establishment (Table 2.3). On average, 158 non-weedy, perennial native forbs grew on seeded plots while 29 grew on unseeded plots. Ellerslie had fewer invading forbs than Oster and Tawayik Lake.

2.2.5 Interactions Between Main Effects

Most interactions between treatment effects were not significant, and only main effects of location, season of seeding and mowing affected native forbs.

2.2.6 Location

Location did not affect total forb establishment and survival in 1998 but had a significant effect by the second growing season (Table 2.4). More forbs established at Ellerslie than at Oster or Tawayik Lake. The number of seeded forbs at Ellerslie increased from the first to the second growing season, while at Oster Lake they increased only slightly and at Tawayik Lake they decreased. At Tawayik Lake, seeded forbs that grew taller than dandelions early in 1998 survived, but few shorter seedlings were present. The number of weedy species was lower at Oster Lake and native forb survival higher.

More smooth aster (*Aster laevis* L.), wild bergamot (*Monarda fistulosa* L.) and low goldenrod (*Solidago missouriensis* L.) established at Ellerslie than at Oster and Tawayik Lake in 1998 and this trend continued to be significant through the second growing season for smooth aster and wild bergamot (Table 2.4). More blanket flower (*Gaillardia aristata* Pursh) and purple prairie clover established at Ellerslie and Oster Lake than at Tawayik Lake in 1998. By the end of the second growing season, Ellerslie had significantly more blanket flower and purple prairie clover than Oster or Tawayik Lake. Wild blue flax and prairie coneflower established in relatively high numbers at all locations. No more than ten Canada goldenrod plants established at any location. Common yarrow and wild vetch establishment did not differ with location in the first growing season. By the second growing season more common yarrow established at Oster and Tawayik Lake than Ellerslie; wild vetch established best at Ellerslie and least at Oster Lake. Yarrow was common at Elk Island where it may have come from the seed bank and invasion. Wild vetch was also in the seed bank and surrounding plant populations at all locations, although wild populations were greater at Oster and Tawayik Lake than Ellerslie. Common yarrow and wild vetch constituted over half the native forbs on the sites. Smooth aster, wild bergamot, purple prairie clover and low goldenrod did not establish on some replicates at some locations, so flowering, seed set and height could not be assessed for these species at all locations (Table 2.4).

The Oster and Tawayik Lake locations may have had slightly better soil moisture conditions for seedling establishment. However, the Ellerslie location also received precipitation during this time, so climate likely was not a major factor in forb

establishment. Soil conditions at the three locations varied, but these variations still fell within the ranges of adaptation for the native forb species used in this research (Appendix D). For example, common yarrow, Canada goldenrod and wild vetch are found in prairie, aspen parkland, boreal forest and montane ecosystems (Looman and Best 1994). Species like wild bergamot have a more limited range, but are still found through the aspen parkland and boreal forest.

Higher soil fertility levels at Tawayik and Oster Lake likely enhanced growth of annual weeds at the expense of native forb seedlings. Wilson and Gerry (1995) found the number of native grass and forb seedlings establishing decreased with increased soil nitrogen levels. Penetration resistance of soil at Oster and Tawayik Lake may also have restricted rooting depth of native forbs, increasing mortality.

Populations and growth of weeds and other invading species differed between locations and appeared to have the greatest impact on native seedling survival. Oster and Tawayik Lake were disturbed more recently than Ellerslie, so more seeds could be in the seedbank. Native plants were closer to plots at Oster and Tawayik Lake than at Ellerslie, and more native species would be expected to invade. High soil nitrogen levels and fewer opportunities for weed control prior to establishment of the plots at Oster and Tawayik Lake likely encouraged growth of weedy species. Total plant density at Tawayik Lake averaged 330 plants m^{-2} in 1998 and 540 plants m^{-2} in 1999 (Pitchford 2000); unseeded species made up 300 and 500 plants m^{-2}, respectively. Total plant density at Oster Lake was 190 plants m^{-2} in 1998 and 180 plants m^{-2} in 1999; unseeded species made up 100 and 150 plants m^{-2}, respectively. Ellerslie had the lowest plant density in 1998 with 70 plants m^{-2}; 50 plants m^{-2} were unseeded. By 1999, plant density at Ellerslie was second highest at 390 plants m^{-2}, 360 of them unseeded.

Annuals, especially tall growing ones, compete for nutrients and light, but are less detrimental to seedling growth than perennials. Perennials, especially low growing ones, are fiercely competitive with seedlings. At Oster Lake, particularly in the first growing season, plant competition came mainly from tall growing annual weeds (maple-leaved goosefoot, lambsquarters and nettle (*Urtica diocia* L.)) with limited competition from low growing perennials like alsike and red clover. After the second growing season, perennial weeds increased, while annual weed cover was low. Ellerslie had low weed

populations, particularly in the first growing season and most competition came from tall growing annual weeds, mainly canola. Competition in the second growing season continued to be from annual and biennial weeds. Weeds at Tawayik Lake in the first growing season were tall growing annuals, predominantly maple-leaved goosefoot and lambsquarters, and a high proportion of low growing perennials, mainly dandelion and alsike clover. By the end of the first growing season and through the second, some replicates had high cover from dandelions.

Location had no effect on forbs that bloomed in 1998, but affected flowering in 1999 (Table 2.5). Fewer than 10% of seeded forbs bloomed at any location in the first growing season. By the second growing season, more forbs bloomed at Oster Lake than Ellerslie or Tawayik Lake. Significantly more common yarrow, blanket flower, wild blue flax, prairie coneflower and Canada goldenrod bloomed the second year at Ellerslie and Oster Lake than at Tawayik Lake. More smooth aster bloomed at Oster Lake than Ellerslie.

Few forbs set seed at any location in 1998 (Table 2.6). By 1999, 35% of forbs set seed on all three locations. In the second growing season, more wild blue flax set seed at Ellerslie and Oster Lake than at Tawayik Lake. Seed set of prairie coneflower was greatest at Ellerslie, less at Tawayik and least at Oster Lake. Only half the forbs that flowered in 1998 set seed, while most that flowered in 1999 set seed. Most seeded native forbs were not mature enough to flower and set seed the first growing season. Native forb seedlings competing with other plants may not set seed for three to four years (Blake 1935). Forbs at Ellerslie and Oster Lake, where competition was lower were more likely to flower than those at Tawayik Lake where competition was heavier.

Location significantly affected forb height after the second growing season (Table 2.7). Forbs were tallest at Oster Lake and shortest at Tawayik Lake. However, wild bergamot was shortest at Oster Lake. Common yarrow, smooth aster, blanket flower, wild bergamot and wild vetch were affected by location. Competition for nutrients and water likely reduced forb height at Tawayik Lake.

Wild blue flax was the most successful seeded native forb after the second growing season in the Northern Great Plains (Depuit and Coenenberg 1979). Purple prairie coneflower, sunflower (*Helianthus annuus* L.), common yarrow and prairie

coneflower also established. These species did well in this study. Many other native forbs were unsuccessful establishing in the Northern Great Plains, including rose (*Rosa woodsii* Lindl.), leadplant (*Amorpha canescens* Pursh), arrowleaf balsamroot (*Balsamorrhiza sagittata* (Pursh) Nutt.), purple coneflower (*Echinacea angustifolia* D.C.) and Montana thermopsis (*Thermopsis montana* Nutt.) (Depuit and Coenenberg 1979).

2.2.7 Season of Seeding

Spring seeding significantly increased native forb establishment over fall seeding after both the first and second growing seasons (Table 2.8). Only smooth aster and low goldenrod established equally well in both seasons. Spring seeding gave better establishment of blanket flower, wild blue flax, purple prairie clover, prairie coneflower and wild vetch in the first growing season. After the second growing season, spring seeding still produced larger populations of blanket flower, wild blue flax, purple prairie clover and prairie coneflower. Establishment of common yarrow by the second growing season was significantly better when spring seeded. Wild bergamot established better when fall seeded, although this effect was only significant by the second growing season.

Purple prairie clover was significantly lower in the second year on spring seeded plots, suggesting they were unable to overwinter, and few new seeds were germinating and establishing in the second year. Common yarrow and prairie coneflower increased on spring seeded plots between 1998 and 1999, but decreased on fall seeded plots. Wild vetch increased more on fall seeded than on spring seeded plots from 1998 to 1999.

Fall seeding increases the risk of seed losses over winter (Munshower 1994) due to decomposition, erosion and predation by rodents and birds (Nelson et al. 1970, Campbell and Swain 1973). Cultivation on spring seeded plots was needed to loosen the seedbed for drill seeding. This killed winter annual weeds and early germinating annuals, possibly giving native forbs an advantage over weeds. Research on various species suggests early emergence gives plants an advantage over competitors in gaining resources (Ross and Harper 1972, Harper 1977, Weaver 1984, O'Donovan et al. 1985).

Several researchers found better survival of native forbs with fall seeding in mid-western USA (Salac et al. 1982, Johnson and Whitwell 1997). In Colorado, Fisher et al. (1987) found October seeding gave better establishment of wild blue flax and Rocky

Mountain penstemon (*Penstemon strictus* Bentley) than spring seeding. In the aspen parkland, precipitation in early spring is normally good and tends to be consistent through May and June. Thus spring seeding should result in good germination and establishment. However, early soil moisture in spring 1998 was low due to drier than average conditions through late summer and fall 1997 and winter 1997/1998. Fall seeded forbs germinating early in spring may have desiccated before the root could reach moisture. While spring and summer 1998 were also drier than average, there may have been enough precipitation to ensure seed germination and establishment on spring seeded plots.

Moist-cold seed treatment (stratification) improves seed germination in many native forbs and fall seeding is used to improve field germination for many forbs. However, moist -cold treatment is not needed for smooth aster, blanket flower, wild blue flax, wild bergamot, prairie coneflower and Canada goldenrod (Currah et al. 1983, Pahl and Smreciu 1999). Currah et al. (1983) found moist-cold treatment improved germination of common yarrow, while Pahl and Smreciu (1999) found this treatment was unnecessary and Sorensen and Holden (1974) found it reduced germination. Moist cold treatment is recommended to improve germination of low goldenrod (Currah et al. 1983) and has little effect on purple prairie clover and wild vetch (Currah et al. 1983, Pahl and Smreciu 1999). Most species in this experiment were not expected to benefit greatly from moist-cold seed treatment from fall seeding and our results support this. The one exception was wild bergamot, which benefited from fall seeding, although Greene and Curtis (1952) found in Wisconsin it germinated better untreated than with moist-cold treatment.

Seeds for the spring seeded treatments were stored dry in a freezer during winter 1997/1998. They may have been exposed to some moist-cold treatment during storage, reducing seed dormancy. Generally, temperature stimulation of germination occurs after seeds have imbibed water and changes to dry stored seeds are relatively unimportant (Meyer et al. 1995). However, Blake (1935) found freezing dry seeds of some native forbs improved germination for common yarrow (*Achillea occidentalis* (D.C.) Raf. ex Rydb.), leadplant, roundheaded bushclover (*Lespedeza capitata* Michx.), prairie blazing star (*Liatris scariosa* (L.) Willd) and some *Penstemon* species.

More forbs were found in the second growing season than in the first, suggesting

germination in several species was spread over at least two years. The greatest increase came from wild vetch. It has a hard seed coat that prevents germination until the coat is broken (Currah et al. 1983, Pahl and Smreciu 1999). Scarification is recommended to increase germination, but the seed used here was not treated. On these plots, many wild vetch plants needed two years to germinate and establish. It is possible that plant numbers will continue to increase for at least a few more years.

Salac and Traeger (1982) put native forbs into three categories based on their response to spring and fall seeding. Some forbs germinated best when seeded in spring, indicating they had little seed dormancy, but fall seeding significantly reduced emergence (e.g. purple prairie clover). They concluded winter soil conditions caused seed damage in this group. The second group emerged best when seeded in late fall. These species appeared to have a low temperature requirement to break dormancy. Other researchers also grouped numerous native forbs in this category (Nichols 1934, Blake 1935). Salac and Traeger (1982) found several native forbs germinated equally well with fall or spring seeding (e.g. greyhead prairie coneflower (*Ratibida pinnata* (Vent.) Barnh.)). These species had no seed dormancy requirements needing cold temperatures, but could survive well over winter. In this experiment, smooth aster, Canada goldenrod and low goldenrod showed no dormancy requirements and survived well over winter. Wild bergamot seemed to have a cold temperature requirement to overcome dormancy. Purple prairie clover, blanket flower and prairie coneflower geminated well when spring seeded, but less so when fall seeded. Common yarrow, wild blue flax and wild vetch established slightly better with spring seeding, but also had some establishment from fall seeding, so damage from fall seeding, while present, was less in these species.

Zajicek et al. (1986) also found time of seeding had a large impact on germination and establishment of native forbs. They found greyhead coneflower emerged better from spring than fall seeding, even though lab studies showed it benefited from moist-cold treatment. Purple prairie clover established significantly better when spring seeded. Greyhead prairie coneflower is similar to prairie coneflower, which also established significantly better with spring seeding in this research. Johnson and Whitwell (1997) had good establishment of common yarrow from both spring and fall seeding, however, blanket flower and prairie coneflower emerged poorly from spring and fall seeding.

Young et al. (1994) found no difference in establishment of "Appar" blue flax between spring and fall seeding in a wet year on arid rangeland.

Few native forbs flowered the first growing season, regardless of season of seeding (Table 2.9). By the second growing season, significantly more fall than spring seeded forbs flowered. Common yarrow was the only species where fall seeding significantly increased the percent of plants that bloomed in the first year. Season of seeding did not affect its flowering by the second growing season. Prairie coneflower, and Canada goldenrod were the only other forbs where a number of plants flowered in the first growing season, and there was no difference between fall and spring seeding. Fall seeding significantly increased flowering of smooth aster, wild blue flax and Canada goldenrod in the second growing season. Season of seeding did not affect blanket flower, purple prairie clover and wild vetch flowering in either growing season.

Significantly more fall than spring seeded forbs set seed in both the first and second growing seasons (Table 2.10). In the first growing season, only common yarrow seed set was significantly affected by season of planting, with higher seed set from fall seeding. In the second growing season, fall seeding increased seed set of smooth aster, wild blue flax, wild bergamot and Canada goldenrod. Season of seeding did not affect seed set of blanket flower, purple prairie clover, prairie coneflower, prairie goldenrod or wild vetch.

Frischknecht (1951) found fall seeding rangeland grasses had little effect on germination and establishment, but the plants appeared to benefit from vernalization (hastening flowering or fruiting by treating seeds to shorten the vegetative period). Fall planted grasses were more likely to flower and set seed during the first growing season, while spring seeded grasses were more likely to stay vegetative. Common yarrow may benefit from vernalization in the first growing season, since more fall than spring seeded plants flowered and set seed. A small, statistically insignificant effect may have occurred in prairie coneflower and Canada goldenrod. If rapid seed production is a reclamation goal, then fall seeding may offer some advantages for these species. While fall seeded plants of some species were more likely to bloom in the second growing season, vernalization did not likely cause this increase, since spring seeded plants had been exposed to winter conditions by that measurement time. Fall seeded plants appeared to

be more mature and advanced than those seeded in the spring.

Overall, native forbs seeded in fall were significantly taller than those seeded in spring after two growing seasons (Table 2.11). Fall seeding resulted in taller smooth aster, wild blue flax, wild bergamot and Canada goldenrod plants. There was no difference in height with season of seeding in the other forbs planted. This also suggests fall seeded forbs were more mature and advanced than spring seeded forbs.

2.2.8 Annual Weed Control by Mowing

Mowing to control annual weeds in the first growing season significantly reduced native forb establishment in the first growing season (Table 2.12). The number of forbs on mowed plots in the second growing season was still lower than on unmowed plots, but the difference was no longer significant. Mowing significantly reduced establishment of smooth aster, low goldenrod and wild vetch in the first growing season. However, after the second growing season, plant numbers on mowed plots caught up. After the second growing season, mowing significantly increased the number of common yarrow plants, although no effect had been seen in the first year.

Interaction between seeding season and mowing significantly affected seeded forbs in 1999 (Table 2.13). Mowing increased establishment on spring seeded plots, but reduced it on fall seeded plots. Common yarrow and smooth aster (*Aster laevis* L.) were the only species with significant mowing by season interactions.

Although height was only measured in 1999, forbs that established from fall seeding may have been tall enough in 1998 to be cut by the mower, reducing leaf area and carbohydrate storage and affecting survival. Common yarrow and smooth aster are relatively tall and could have been cut by mowing. Less weed growth on spring seeded plots would give less litter after mowing. This litter may have been thick enough on fall seeded plots to choke out some seedlings. Spring seeded plots also had fewer biennial and perennial weeds due to additional cultivation.

There was a significant location by mowing interaction effect on common yarrow in 1999 (Table 2.14). Mowing increased common yarrow at Oster and Tawayik Lakes, but had no effect at Ellerslie. Mowing may have reduced plant competition, increasing opportunities for invasion from common yarrow in the seed bank in these locations. At

Ellerslie, plots were situated in cultivated cropland, so opportunities for invasion were limited. Common yarrow is an aggressive species and by the second year appeared to be able to establish better where mowing reduced competition.

Reducing plant competition by cutting annual weeds did not enhance germination, establishment or survival for most native forbs seeded. Annual weeds did not reduce forb establishment as much as mowing. They may even have enhanced establishment of native forbs, as found by Allen (1990). Damage from mowing could have resulted from cutting the forbs, accumulation of litter or a combination of the two. Less competitive forbs were unable to recover as well as perennial grasses and weedy species.

Mowing did not affect the percent of forbs that bloomed in either growing season (Table 2.15). By the second growing season, it significantly increased the likelihood of flowering of common yarrow, but reduced it for wild blue flax and low goldenrod. Mowing had no effect on flowering of other forbs. Mowing significantly reduced the percent of forbs that set seed in 1998, but the effect was no longer significant by 1999 (Table 2.16). Mowing reduced the percent of common yarrow that set seed in 1998, but not in 1999. Mowing wildflowers may extend the blooming period, likely by releasing apical dominance (Hesse and Salac 1972). The forbs in this research generally were not mature enough to bloom the first growing season, so mowing did not affect flowering. However, removing apical dominance may have promoted more tillers the first year.

Mowing reduced seeded forb height in 1998, since the mower cut many plants, but no height data were collected. Mowing in the first year had no impact on average forb height by the second growing season (Table 2.17). However, by 1999, mowed Canada goldenrod plants were significantly taller than unmowed plants. In 1999 mowed wild vetch plants were shorter than unmowed ones. The interaction between season of seeding and mowing significantly affected height of wild blue flax and total forbs in 1999 (Table 2.13). Mowing increased plant height on fall seeded plots, but reduced it on spring seeded plots. This interaction was not significant for any other forb species.

2.3 Practical Applications

Annual weed competition appeared to impact forb establishment and growth

differently than perennial weed competition. The first growing season, annual weeds had no negative effect on establishment and may have improved it. By the second season, seeded species provided enough cover to eliminate most annuals. However, low growing perennials like dandelion and clover reduced forb establishment and affected community development. Adequate weed control, particularly of perennials, is required when seeding native forbs.

Spring seeding provided better native forb establishment and survival for all species tested except wild bergamot. However, fall seeding still resulted in good forb seedling establishment. If fall seeding is the best option for a site, a higher seeding rate may compensate for poorer establishment. Native forb seed has high dormancy and seeds remain viable for several years. Forb seeds continued to germinate and grow over both years of this experiment, increasing the number of forbs over time.

Common yarrow and wild vetch invaded plots where they were present in the surrounding plant populations, and the seed bank could contain high levels of seed. On sites where invasion is likely, lower amounts of seed from aggressive species could be used since they will quickly move into the plots after seeding. Less aggressive forbs will be slower to invade, even where plant populations are relatively high in the area.

Seeding native forbs with the grass mix may limit options for weed control. In a native grass stand, herbicides can be used to control weeds early in the establishment period. However, including native forbs limits weed control options, and may limit reclamation success. Forb selection will also be limited to those species that start well from seed and are available commercially.

2.4 Conclusions

Previous site management, in association with location within the aspen parkland, changed seed bank and plant invasion potential. This determined plant competition on the site, which significantly affected seeded native forb establishment, survival and floral reproduction in the first two growing seasons. Perennial weeds appeared to have a greater impact on seeded native forb establishment than annuals.

Mowing in the first growing season to control annual weeds reduced

establishment and survival of seeded native forbs for the first two growing seasons.

Spring seeding improved seeded native forb establishment and survival in the first two growing seasons. Fall seeded plants matured earlier and were more likely to produce seed in the first two growing seasons.

A number of perennial native forbs invaded from the seed bank and surrounding vegetation, but only relatively low numbers were found in the first two growing seasons.

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Table 2.1 Species seeded and seeding rate used for research sites.

Common Name	Scientific Name	Seeding Rate ($g\ plot^{-1}$)	($g\ m^{-2}$)
Northern wheatgrass	*Agropyron dasystachyum* (Hook) Scribn.[1]	12.29	110.00
Slender wheatgrass	*Agropyron trachycaulum* (Link) Malte var. *trachycaulum*	10.28	92.30
Blue grama grass	*Bouteloua gracilis* (HBK) Lag.	1.72	15.50
Plains rough fescue	*Festuca scabrella* Torr.	7.25	65.00
June grass	*Koeleria macrantha* (Ledeb.) J.A. Schultes f.	0.82	7.30
Green needle grass	*Stipa viridula* Trin.	6.35	57.00
Common yarrow	*Achillea millefolium* L.	0.12	1.04
Smooth aster	*Aster laevis* L.	0.81	7.24
Blanket flower	*Gaillardia aristata* Pursh	2.64	23.66
Wild blue flax	*Linum lewisii* Pursh	1.36	12.21
Wild bergamot	*Monarda fistulosa* L.	0.48	4.34
Purple prairie clover	*Petalostemon purpureum* (Vent.) Rydb.	1.35	12.09
Prairie coneflower	*Ratibida columnifera* (Nutt.) Wooton & Standl.	1.81	16.26
Canada goldenrod	*Solidago canadensis* L.	0.68	6.11
Low goldenrod	*Solidago missouriensis* Nutt.	0.89	7.96
Wild vetch	*Vicia americana* Muhl.	9.72	87.30
Total forb seed		19.85	178.21
Total seed		58.55	525.30

[1] Plant names according to Moss 1992.

Table 2.2 Average number of plants and percent of pure live seeds planted that produced a live plant in the first and second growing season.

		% PLS establishing		Plants present $plot^{-1}$		Plants m^{-2}	
Common Name	Scientific Name	1998	1999	1998	1999	1998	1999
Common yarrow	*Achillea millefolium*	6.63	7.12	44	48	0.40	0.43
Smooth aster	*Aster laevis*	0.73	0.86	5	6	0.04	0.05
Blanket flower	*Gaillardia aristata*	1.62	1.81	11	12	0.10	0.11
Wild blue flax	*Linum lewisii*	2.72	2.39	18	16	0.16	0.14
Wild bergamot	*Monarda fistulosa*	0.79	1.00	5	7	0.04	0.06
Purple prairie clover	*Petalostemon purpureum*	1.30	0.32	9	2	0.08	0.02
Prairie coneflower	*Ratibida columnifera*	2.83	3.70	19	25	0.17	0.22
Canada goldenrod	*Solidago canadensis*	0.69	1.11	5	7	0.04	0.06
Low goldenrod	*Solidago missouriensis*	0.61	0.36	4	2	0.04	0.02
Wild vetch	*Vicia americana*	6.08	11.52	41	77	0.37	0.69
Average Overall		2.40	3.02	160	202	1.44	1.81

Table 2.3 Number of native forbs on seeded and unseeded plots at Ellerslie, Oster Lake and Tawayik Lake in 1998.

		Mean	S.D.
Ellerslie	Seeded	166 a[1]	73
	Unseeded	1 c	3
Oster Lake	Seeded	154 a	90
	Unseeded	31 b	14
Tawayik Lake	Seeded	155 a	98
	Unseeded	55 b	36

[1] Means followed by the same letter are not significantly different (P<0.10).

Table 2.4 Effect of location on number of seeded native forbs in 1998 and 1999.

					1998 Ellerslie		1998 Oster		1998 Tawayik		1999 Ellerslie		1999 Oster		1999 Tawayik	
Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.39	0.14	0.06	20	10	64	29	73	51	21 b	11	76 a	37	73 a	43
Smooth aster	*Aster laevis*	0.16	0.01	0.07	9 a[4]	6	2 b	2	0 b	0	10 a	7	2 b	2	0 b	1
Blanket flower	*Gaillardia aristata*	0.07	0.01	0.01	15 a	8	11 a	10	3 b	3	18 a	10	10 b	9	1 c	2
Wild blue flax	*Linum lewisii*	0.57	0.31	0.12	21	11	19	11	13	8	20	12	16	11	8	6
Wild bergamot	*Monarda fistulosa*	0.47	0.01	0.01	10 a	6	0 b	1	1 b	1	13 a	8	0 b	1	1 b	1
Purple prairie clover	*Petalostemon purpureum*	0.09	0.07	0.01	11 a	10	10 a	15	2 b	3	4 a	4	0 b	0	0 b	0
Prairie coneflower	*Ratibida columnifera*	0.51	0.42	0.30	27	40	17	20	5	6	32	45	28	32	6	7
Canada goldenrod	*Solidago canadensis*	0.07	0.13	0.14	6	4	5	7	1	1	10	8	9	11	1	1
Low goldenrod	*Solidago missouriensis*	0.55	0.01	0.14	6 a	4	2 b	2	2 b	3	4	3	1	1	0	0
Wild vetch	*Vicia americana*	0.01	0.19	0.09	42	20	24	17	55	58	117 a	64	19 c	15	56 b	50
Total Present		0.01	0.94	0.05	166	73	154	90	155	98	251 a	95	160 b	96	144 b	71

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

[4] Within each year and across rows, means followed by the same letter are not significantly different ($P<0.10$).

Table 2.5 Effect of location on percent of seeded native forbs that bloomed in 1998 and 1999.

					1998 Ellerslie		1998 Oster		1998 Tawayik		1999 Ellerslie		1999 Oster		1999 Tawayik	
Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean[4]	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.01	0.96	0.01	12	14	12	11	11	16	92 a[5]	9	88 a	9	56 b	15
Smooth aster	*Aster laevis*	0.01	0.21	0.01	4	8	22	38			58	30	95	8		
Blanket flower	*Gaillardia aristata*	0.01	0.45	0.01	1	3	0	0	0	0	70 a	14	78 a	20	45 b	44
Wild blue flax	*Linum lewisii*	0.01	0.49	0.02	5	7	3	4	2	5	87 a	9	86 a	14	67 b	25
Wild bergamot	*Monarda fistulosa*	0.68	NA	0.57	0	0			0	0	10	17			0	0
Purple prairie clover	*Petalostemon purpureum*	NA	NA	NA	0	1					5	15				
Prairie coneflower	*Ratibida columnifera*	0.02	0.94	0.09	11	19	18	19	15	10	61	35	64	14	25	6
Canada goldenrod	*Solidago canadensis*	0.19	0.65	0.09	5	17	9	15	0	0	37	30	40	25	0	0
Low goldenrod	*Solidago missouriensis*	0.19	NA	0.51	0	0	0	0			29	33	0	0		
Wild vetch	*Vicia americana*	0.16	0.31	0.42	0	0	1	2	1	4	9	10	7	14	20	26
Total Present		0.05	0.44	0.03	4	10	7	14	4	9	47 b	38	59 a	37	39 b	32

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

[4] Blank indicates not enough plants survived on each replicate to assess characteristic at this location.

[5] Within each year and across rows, means followed by the same letter are not significantly different (P<0.10).

Table 2.6 Effect of location on percent of seeded native forbs that set seed in 1998 and 1999.

Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	1998 Ellerslie Mean	S.D.	1998 Oster Mean[4]	S.D.	1998 Tawayik Mean	S.D.	1999 Ellerslie Mean	S.D.	1999 Oster Mean	S.D.	1999 Tawayik Mean	S.D.
Common yarrow	*Achillea millefolium*	0.11	0.14	0.27	4	9	5	7	5	8	49	19	44	18	30	16
Smooth aster	*Aster laevis*	0.10	0.13	0.64	0	0	11	19			54	32	26	25		
Blanket flower	*Gaillardia aristata*	0.37	NA	0.75	0	0	0	0	0	0	70	14	56	35	65	41
Wild blue flax	*Linum lewisii*	0.03	0.84	0.02	2	5	1	3	2	5	87 a[5]	9	84 a	14	67 b	25
Wild bergamot	*Monarda fistulosa*	0.68	NA	0.57	0	0			0	0	10	17			0	0
Purple prairie clover	*Petalostemon purpureum*	NA	NA	NA	0	1					4	14				
Prairie coneflower	*Ratibida columnifera*	0.02	0.86	0.10	2	7	5	8	5	10	28	17	6 b	6	15	14
Canada goldenrod	*Solidago canadensis*	0.04	0.36	0.16	0	0	1	2	0	0	27	34	14	16	0	0
Low goldenrod	*Solidago missouriensis*	0.32	NA	0.53	0	0	0	0			12	17	0	0		
Wild vetch	*Vicia americana*	0.18	0.25	0.42	0	0	0	0	1	4	9	10	7	14	20	26
Total Present		0.75	0.22	0.94	1	4	2	6	2	6	37	34	34	34	35	33

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.
[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.
[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.
[4] Blank indicates not enough plants survived on each replicate to assess characteristic at this location.
[5] Within each year and across rows, means followed by the same letter are not significantly different ($P<0.10$).

Table 2.7 Effect of location on average height (cm) of seeded native forbs in 1999.

Common Name	Scientific Name	P 1999[1]	1999 Ellerslie Mean	S.D.	1999 Oster Mean[2]	S.D.	1999 Tawayik Mean	S.D.
Common yarrow	*Achillea millefolium*	0.02	65 a[3]	9	67 a	7	49 b	7
Smooth aster	*Aster laevis*	0.04	36	17	60	23	24	8
Blanket flower	*Gaillardia aristata*	0.01	60	12	75	15	43	17
Wild blue flax	*Linum lewisii*	0.17	51	9	60	7	46	14
Wild bergamot	*Monarda fistulosa*	0.09	22 a	6	8 b		17 a	7
Purple prairie clover	*Petalostemon purpureum*	NA	26	9				
Prairie coneflower	*Ratibida columnifera*	0.22	47	15	50	10	34	7
Canada goldenrod	*Solidago canadensis*	0.13	44	15	45	10	30	25
Low goldenrod	*Solidago missouriensis*	0.68	25	12	20	5		
Wild vetch	*Vicia americana*	0.01	42 a	5	43 a	7	34 b	6
Total Present		0.01	42 b	18	54 a	18	38 c	15

[1] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

[2] Blank indicates not enough plants survived on each replicate to assess characteristic at this location.

[3] Within each year and across rows, means followed by the same letter are not significantly different (P<0.10).

Table 2.8 Effect of season of seeding on number of seeded native forbs in 1998 and 1999.

Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	1998 Fall Mean	S.D.	1998 Spring Mean	S.D.	1999 Fall Mean	S.D.	1999 Spring Mean	S.D.
Common yarrow	*Achillea millefolium*	0.09	0.22	0.08	38	41	50	36	36	36	59	40
Smooth aster	*Aster laevis*	0.91	0.78	0.84	5	6	5	6	5	6	6	8
Blanket flower	*Gaillardia aristata*	0.75	0.01	0.05	6	7	16	9	7	9	17	11
Wild blue flax	*Linum lewisii*	0.75	0.05	0.06	14	11	22	9	13	9	20	13
Wild bergamot	*Monarda fistulosa*	0.60	0.19	0.03	6	7	4	6	8	10	5	6
Purple prairie clover	*Petalostemon purpureum*	0.01	0.01	0.01	1	2	16	11	1	1	4	5
Prairie coneflower	*Ratibida columnifera*	0.10	0.05	0.02	1	1	37	35	0	1	49	39
Canada goldenrod	*Solidago canadensis*	0.03	0.59	0.25	4	4	5	6	5	4	10	11
Low goldenrod	*Solidago missouriensis*	0.11	0.25	0.29	3	4	5	4	2	3	3	3
Wild vetch	*Vicia americana*	0.08	0.01	0.29	24	20	57	37	71	80	82	52
Total Present		0.71	0.01	0.01	102	50	218	62	149	101	255	69

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.
[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.
[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

Table 2.9 Effect of season of seeding on percent of seeded native forbs that bloomed in 1998 and 1999.

					1998 Fall		1998 Spring		1999 Fall		1999 Spring	
Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.02	0.01	0.17	21	14	3	3	86	21	78	15
Smooth aster	*Aster laevis*	0.01	0.21	0.05	7	10	6	20	78	15	53	36
Blanket flower	*Gaillardia aristata*	0.88	0.85	0.94	1	2	1	2	73	29	64	23
Wild blue flax	*Linum lewisii*	0.01	0.69	0.04	4	6	3	6	90	8	74	20
Wild bergamot	*Monarda fistulosa*	0.15	1.00	0.42	0	0	0	0	5	11	15	21
Purple prairie clover	*Petalostemon purpureum*	0.01	NA	NA	0	0	1	1	13	25	2	4
Prairie coneflower	*Ratibida columnifera*	0.03	0.58	0.21	30	42	12	15	25	35	57	28
Canada goldenrod	*Solidago canadensis*	0.07	0.40	0.02	9	20	3	9	46	33	20	19
Low goldenrod	*Solidago missouriensis*	0.01	1.00	0.10	0	0	0	0	57	28	6	14
Wild vetch	*Vicia americana*	0.14	0.69	0.23	1	3	0	1	15	22	7	9
Total Present		0.03	0.22	0.01	6	13	3	9	56	37	42	36

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

Table 2.10 Effect of season of seeding on percent of seeded native forbs that set seed in 1998 and 1999.

					1998 Fall		1998 Spring		1999 Fall		1999 Spring	
Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.63	0.10	0.12	9	10	1	2	49	24	37	11
Smooth aster	*Aster laevis*	0.01	0.47	0.03	0	0	3	10	78	15	30	25
Blanket flower	*Gaillardia aristata*	0.70	1.00	0.75	0	0	0	0	73	29	62	23
Wild blue flax	*Linum lewisii*	0.01	0.13	0.01	3	6	0	1	89	9	74	20
Wild bergamot	*Monarda fistulosa*	0.15	1.00	0.01	0	0	0	0	17	17	0	0
Purple prairie clover	*Petalostemon purpureum*	0.01	NA	NA	0	0	0	0	13	25	0	0
Prairie coneflower	*Ratibida columnifera*	0.12	0.49	0.56	10	14	3	7	0	0	21	16
Canada goldenrod	*Solidago canadensis*	0.01	0.25	0.05	0	0	0	1	32	36	8	14
Low goldenrod	*Solidago missouriensis*	0.35	1.00	0.55	0	0	0	0	20	20	4	10
Wild vetch	*Vicia americana*	0.16	0.35	0.23	1	3	0	1	15	22	7	9
Total Present		0.01	0.04	0.01	2	6	1	4	46	36	28	30

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

Table 2.11 Effect of season of planting on height (cm) of seeded native forbs in 1999.

Common Name	Scientific Name	P 1999	1999 Fall Mean	S.D.	1999 Spring Mean	S.D.
Common yarrow	*Achillea millefolium*	0.12	64	10	58	11
Smooth aster	*Aster laevis*	0.01	48	17	31	22
Blanket flower	*Gaillardia aristata*	0.59	69	15	57	17
Wild blue flax	*Linum lewisii*	0.10	55	10	49	12
Wild bergamot	*Monarda fistulosa*	0.02	26	4	16	6
Purple prairie clover	*Petalostemon purpureum*	NA	24	10	27	8
Prairie coneflower	*Ratibida columnifera*	0.74	43	7	46	14
Canada goldenrod	*Solidago canadensis*	0.01	49	17	35	12
Low goldenrod	*Solidago missouriensis*	0.13	35	7	19	8
Wild vetch	*Vicia americana*	0.91	40	8	40	5
Total Present		0.03	49	17	40	18

[1] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

Table 2.12 Effect of mowing on number of seeded native forbs in 1998 and 1999.

					1998 Unmowed		1998 Mowed		1999 Unmowed		1999 Mowed	
Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.39	0.83	0.03	44	44	45	33	45	36	50	43
Smooth aster	*Aster laevis*	0.29	0.04	0.54	7	8	3	3	6	7	5	7
Blanket flower	*Gaillardia aristata*	0.40	0.18	0.51	13	10	9	8	13	11	11	11
Wild blue flax	*Linum lewisii*	0.61	0.22	0.72	21	11	16	10	18	13	14	10
Wild bergamot	*Monarda fistulosa*	0.55	0.12	0.79	7	7	4	6	7	9	6	8
Purple prairie clover	*Petalostemon purpureum*	0.34	0.22	0.60	7	8	10	13	2	3	3	4
Prairie coneflower	*Ratibida columnifera*	0.60	0.62	0.72	21	34	17	28	25	39	25	35
Canada goldenrod	*Solidago canadensis*	0.25	0.11	0.82	6	6	3	4	8	9	7	9
Low goldenrod	*Solidago missouriensis*	0.02	0.02	0.61	6	5	3	3	3	3	2	3
Wild vetch	*Vicia americana*	0.85	0.01	0.13	49	40	32	24	90	78	64	52
Total Present		0.52	0.09	0.53	179	85	142	75	215	104	188	99

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

Table 2.13 Effect of interaction between season of seeding and mowing on plants and average height in 1999.

		Plants present Total			Average height Common yarrow (*Achillea millefolium*)			Smooth aster (*Aster laevis*)			Overall			Blue flax (*Linum lewisii*)		
Season	Mowed	P 1999[1]	Mean	S.D.	P 1999	Mean	S.D.	P 1999	Mean	S.D.	P 1999	Mean	S.D.	P 1999	Mean	S.D.
Fall	No	0.09	187	119	0.03	36	38	0.07	7	7	0.01	45	16	0.01	50	10
Fall	Yes		114	70		36	35		4	4		53	18		60	7
Spring	No		246	82		54	34		5	7		42	20		53	15
Spring	Yes		263	57		65	47		7	9		39	16		45	7

[1] P 1999 value is the probability that the difference between locations happened by chance.

Table 2.14 Effect of interaction between location and mowing on common yarrow in 1999.

		Common yarrow (*Achillea millefolium*)		
Location	Mowed	P 1999[1]	Mean	S.D.
Ellerslie	No	0.05	21 c[2]	12
Ellerslie	Yes		21 c	11
Oster Lake	No		66 b	34
Oster Lake	Yes		85 a	43
Tawayik Lake	No		71 b	44
Tawayik Lake	Yes		75 b	48

[1] P 1999 value is the probability that the difference between locations happened by chance.
[2] Means followed by the same letter are not significantly different ($P<0.10$).

Table 2.15 Effect of mowing on percent of seeded native forbs that bloomed in 1998 and 1999.

Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	1998 Unmowed Mean	S.D.	1998 Mowed Mean	S.D.	1999 Unmowed Mean	S.D.	1999 Mowed Mean	S.D.
Common yarrow	*Achillea millefolium*	0.06	0.30	0.05	13	15	10	12	80	19	85	18
Smooth aster	*Aster laevis*	0.04	0.24	0.28	11	21	2	7	62	32	65	32
Blanket flower	*Gaillardia aristata*	0.28	0.81	0.04	0	2	1	3	68	24	66	28
Wild blue flax	*Linum lewisii*	0.84	0.49	0.55	4	7	3	5	83	18	81	17
Wild bergamot	*Monarda fistulosa*	0.42	1.00	0.42	0	0	0	0	5	11	15	21
Purple prairie clover	*Petalostemon purpureum*	0.55	NA	NA	0	0	1	2	8	20	2	5
Prairie coneflower	*Ratibida columnifera*	0.71	0.87	0.80	16	21	12	11	49	35	59	21
Canada goldenrod	*Solidago canadensis*	1.00	0.61	0.62	4	10	8	20	33	31	33	29
Low goldenrod	*Solidago missouriensis*	0.04	1.00	0.04	0	0	0	0	33	36	12	21
Wild vetch	*Vicia americana*	0.14	0.50	0.16	1	3	0	1	15	22	7	7
Total Present		0.69	0.41	0.88	5	12	4	10	48	37	48	37

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

Table 2.16 Effect of mowing on percent of seeded native forbs that set seed in 1998 and 1999.

					1998 Unmowed		1998 Mowed		1999 Unmowed		1999 Mowed	
Common Name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.83	0.03	0.25	8	10	2	3	46	19	40	20
Smooth aster	*Aster laevis*	0.03	0.35	0.13	3	1	0	0	42	30	59	34
Blanket flower	*Gaillardia aristata*	0.21	1.00	0.21	0	0	0	0	75	15	56	32
Wild blue flax	*Linum lewisii*	0.85	0.72	0.76	2	5	1	4	82	18	80	17
Wild bergamot	*Monarda fistulosa*	0.42	1.00	0.42	0	0	0	0	5	11	15	21
Purple prairie clover	*Petalostemon purpureum*	0.01	1.00	NA	0	0	0	0	8	20	0	0
Prairie coneflower	*Ratibida columnifera*	0.14	0.83	0.17	4	8	3	7	13	16	26	16
Canada goldenrod	*Solidago canadensis*	0.22	0.35	0.24	0	1	0	0	18	30	22	29
Low goldenrod	*Solidago missouriensis*	0.12	1.00	0.12	0	0	0	0	12	19	7	12
Wild vetch	*Vicia americana*	0.16	0.26	0.16	1	3	0	0	15	22	7	7
Total Present		0.67	0.05	0.48	2	6	1	3	36	34	36	33

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

Table 2.17 Effect of mowing on average height (cm) of seeded native forbs in 1999.

Common Name	Scientific Name	P 1999[1]	1999 Unmowed Mean	S.D.	1999 Mowed Mean	S.D.
Common yarrow	*Achillea millefolium*	1.00	61	11	62	11
Smooth aster	*Aster laevis*	0.53	38	21	42	21
Blanket flower	*Gaillardia aristata*	0.11	63	15	49	19
Wild blue flax	*Linum lewisii*	0.91	52	12	52	10
Wild bergamot	*Monarda fistulosa*	1.00	22	5	20	9
Purple prairie clover	*Petalostemon purpureum*	NA	23	28	28	10
Prairie coneflower	*Ratibida columnifera*	0.70	44	16	47	9
Canada goldenrod	*Solidago canadensis*	0.08	39	15	46	18
Low goldenrod	*Solidago missouriensis*	0.43	26	12	22	10
Wild vetch	*Vicia americana*	0.01	43	6	38	6
Total Present		0.99	44	18	45	19

[1] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

CHAPTER 3 TRANSPLANTED NATIVE FORB ESTABLISHMENT ON DISTURBED ASPEN PARKLAND

3.1 Introduction

Native plant species are being used to reclaim a growing number of industrial disturbances. While use of several native grasses is common, few native forbs have been used for reclamation. Seed supply for native forbs is limited and expensive, seed germination is often low and little information is available on establishment (Blake 1935, Sorensen and Holden 1974, Voight 1977, Bjugstad and Whitman 1989).

Forbs are an important part of plant diversity in native prairie ecosystems (Cook 1983, Bjugstad and Whitman 1989, Gerling et al. 1996) and provide a variety of niches for other life forms. Many native forbs are pioneer species and help rehabilitate disturbed sites by preventing soil erosion and improving nutrient cycling (Salac and Hess 1975, Zajicek et al. 1986, Bjugstad and Whitman 1989). They add aesthetic appeal to the reclaimed landscape by providing contrast, color and interest and help blend the disturbed site into surrounding vegetation.

Native forbs used for reclamation are commonly seeded the same time as grasses (Salac and Hesse 1975, Zajicek et al. 1986). However, they are often hard to establish from seed because of insufficient seeding rates, poor germination, inability of seedlings to compete with grasses and improper management (Zajicek et al. 1986). Field germination and survival are low (Currah et al. 1983, Wallace et al. 1986, Bjugstad and Whitman 1989) and emergence is often slow. Many germinate better with seed treatments requiring controlled conditions. Controlled conditions in greenhouses during early growth stages can also increase forb survival (Hartmann et al. 1997, Wallace et al. 1986) but at an increased cost (Wallace et al. 1986, Morgan et al. 1995).

Native forb transplants bypass germination and establishment problems of field seeding, but weed control is still a concern (Harkness and Lyons 1997); herbicides provide control but may kill or damage many perennial forbs (Derr 1993). Research on survival and growth of native forb transplants on reclamation sites is limited. Clements and Young (2000) found transplanting container-grown antelope bitterbrush (*Purshia tridentata* (Pursh) DC) reintroduced these shrubs into rangeland, while direct seeding was

unsuccessful. Survival of bareroot transplants was low, since most root hairs were removed when the plants were cut. Bjugstad and Whitman (1989) transplanted 14 native forb species into spoil in western North Dakota in June. They survived and grew well the first growing season. Densmore and Holmes (1987) found high survival (73 to 100%) of containerized native seedlings transplanted onto alpine and subalpine sites in Alaska with plants growing vigorously the first year, even in hot, dry weather. Survival of spring planted big sagebrush (*Artemisia tridentata* Nutt.) was high (Evans and Young 1990). Water sedge (*Carex aquatilis* Wahl.) seedlings planted into high elevation mined peat fen survived with good moisture (Cooper and MacDonald 2000).

This research examined survival, growth and reproduction of 12 native forbs transplanted onto disturbed aspen parkland. Most of the parkland is used for agricultural production; less than 5% remains as natural habitat (Morgan et al. 1995). The remaining portions are threatened by invading introduced species and increased disturbances, making research into reestablishing these native plant communities critical.

3.2 Research Objectives

The research objectives were:

1. To assess survival and reproductive potential of selected transplanted native forbs in three locations in the aspen parkland.
2. To compare survival and reproductive potential of selected native forbs transplanted in spring to those transplanted in fall.
3. To compare survival and reproductive potential of selected transplanted native forbs growing with annual weed competition to those mowed to control weeds.

3.3 Research Site Description

Research sites were located at the University of Alberta Ellerslie Research Station (53° 27' 1" N, 113 ° 37' 56" W) on the south edge of Edmonton, Alberta and adjacent to Oster Lake (53 ° 37' 30" N, 112 ° 55' 10" W) and Tawayik Lake (53 ° 36' 37" N, 112 ° 53' 41" W) in Elk Island National Park, 37 km east of Edmonton.

The Ellerslie Research Station is located in the Aspen Parkland Ecoregion (Strong and Leggat 1992). This area is the climatic and ecological transition zone between the boreal forest and grassland areas and covers about 8% of Alberta. A mixture of Black and Dark Gray Chernozemic soils and native grassland and deciduous forest communities form a parkland. The grassland community historically was dominated by rough fescue (*Festuca scabrella* Torr), bluebunch fescue (*Festuca idahoensis* Elmer), June grass (*Koeleria macrantha* (Ledeb.) J.A. Schultes f.) and needle grasses (*Stipa* spp.). Trembling aspen (*Populus tremuloides* Michx.), saskatoon (*Amelanchier alnifolia* Nutt.) and willows (*Salix* spp.) form the major tree component of the community. The research site is located in the prairie-boreal climatic region (Strong and Leggat, 1992). Average summer temperature in this climatic region is 14.4 °C, ranging from 7.7 to 20.9 °C. Average winter temperature is -8.7 °C, ranging from -14 to -3.7 °C. Mean annual temperature is 3.3 °C. Total annual precipitation averages 412 mm, with 259 mm falling in summer. The research site has been used for agricultural research for ten years, using a crop fallow rotation (Appendix A).

Elk Island National Park is located in the Beaver Hill Upland, in the Low Boreal Mixedwood Ecoregion and the boreal climatic region (Strong and Leggat 1992). Average summer temperature in this climatic region is 13.8 °C, ranging from 7.0 to 20.4 °C. Average winter temperature is -10.5 °C, ranging from -15.8 to -5.3 °C. Mean annual temperature is 0.8 °C. Total annual precipitation is 380 mm, with 235 mm falling in summer. The Oster Lake area is dominated by trembling aspen with balsam poplar (*Populus balsamifera* L.) on wetter sites (Crown 1977). The area has a dense shrub layer. The Tawayik Lake area is more open with areas of grassland mixed with aspen stands (Crown 1977). The research sites were located in overgrazed areas with a high proportion of invader species (Bush 1998) (Appendix A).

3.4 Materials and Methods

3.4.1 Experimental Design and Treatments

The experimental design was a complete randomized split block with replications. Four blocks were located at the Ellerslie Research Station, and two blocks each at Oster

Lake and Tawayik Lake in Elk Island National Park. Each block was 8.84 m long and 12.6 m wide with 1 m borders on all sides. Main treatment compared season of seeding, with half seeded in spring and half seeded in fall. Within each block, half of each fall and spring seeded plot was randomly assigned to either a mowed (to control annual weeds and open the canopy) or an unmowed treatment.

Plots were drill seeded at 200 PLS m^{-2} to a native grass mix of six species (Table 3.1) with equal numbers of pure live seeds (PLS) from each species. Nursery-grown seedlings of 12 native forb species were transplanted onto the plots (Table 3.1). Forb species abundant in native aspen parkland communities for which container-grown plants were available were selected.

The fall treatment was seeded with the native grass mix October 4 and 5 and forbs were transplanted October 11 and 12, 1997. The spring treatment was seeded with grass May 24 and forbs transplanted May 25, 1998. Late fall establishment dates were selected so seeds and plants would not germinate or grow until spring, but before snow and frost prevented seeding. Late spring establishment dates were selected to optimize soil moisture levels, rainfall potential and soil temperatures for germination and establishment.

Mowed plots were cut to a height of 10 to 15 cm twice during the first growing season on June 21 and August 5, 1998 with a tractor-drawn, six-foot flail mower. Mowing was timed to prevent the majority of weeds from setting seed. Plots were not mowed in 1999 because annual weed growth was much reduced. The mowing treatment was introduced after forbs were planted. Transplants were randomly located by species within season plots as a whole, but not within mowed halves. Since there was no assurance that all species of transplants were present in equal numbers in mowed and unmowed treatments, mowing effects on individual forb species could not be statistically determined.

3.4.2 Site Establishment

In August 1997, sites were rototilled to a depth of 15 cm. Plant regrowth was sprayed with 3 L ha^{-1} of glyphosate (Roundup) in late August. Sites were rototilled again in early September and regrowth sprayed with glyphosate on September 29, 1997. On

May 24, 1998, immediately prior to seeding, spring seeded treatments were rototilled to the same depth. No fertilizer was added, although the Ellerslie site had been fertilized in the past (Appendix A). A 10 m wide strip around the site perimeter at Ellerslie was cultivated several times in summers 1998 and 1999 as required by research station policy. Plot borders at Ellerslie were mowed in 1998 to facilitate access. No cultivation was done around plots at Oster and Tawayik Lakes, but the area within the fence not used for research was mowed in summer 1998.

The grass mix seeding rate was lower than recommended for industrial disturbances in the area (Munshower 1994, Wark et al. 1995) to facilitate invasion from native species off site. The grass mix was seeded with an eight-cone drill seeder. Details on preparation and seeding are given in Pitchford (2000). ALCLA Native Plant Restoration Inc. of Calgary, Alberta grew the native forb seedlings. Fall planted seedlings were started in the greenhouse in spring 1997. Spring planted seedlings were started early in spring 1998. Seedlings were grown in Ray Leach Cone-trainers, 3.8 cm in diameter and 14 cm deep. Prior to planting, seedlings were shipped by bus from Calgary to Edmonton and stored in a cool, dark location for no more than four days. At planting, seedlings were manually removed from their containers and immediately planted into a hole prepared with a spade or transplanting tool. The seedling was placed in the hole so the potting mixture was at or slightly below the soil surface. The soil was firmed by hand around the seedling. Transplants were not watered.

In each season plot, a total of 105 seedlings were placed in a grid pattern, twelve rows long and nine rows across for a 1 by 1 m spacing between rows and between seedlings in each row. Species were planted at random through this grid. Number of seedlings planted varied with species. Forb species that would normally be present in greater numbers in the Aspen Parkland were included in higher proportions than species that occur more sporadically (Table 3.1). Two common yarrow (*Achillea millefolium* L.) plants were used in each plot even though it is common because yarrow is easily established and very competitive on reclamation sites.

Canada thistle (*Cirsium arvense* (L.) Scop.) invasion became a problem at Ellerslie early in 1998. Since Canada thistle can be very competitive each plant was spot sprayed by hand with a 1:50 concentration of glyphosate periodically through the 1998

and 1999 growing seasons. The research plots at Ellerslie were located with other field crop research plots, and grazing by large herbivores was not expected to be a problem. The sites at Elk Island National Park were fenced to prevent grazing by large herbivores.

3.4.3 Field Sampling and Assessment

3.4.3.1 Soils

Random soil cores were taken from the borders between plots at eight locations per block on May 15, 1998. Cores were taken at 1 to 5, 5 to 15, 15 to 30, 30 to 45 and 45 to 60 cm increments. The eight samples for each increment in each block were bulked to give one sample per block for each of the five depths (40 samples). Samples were air dried prior to analyses. Samples were analyzed for exchangeable nitrate and ammonium nitrogen using a 5:1 potassium chloride extract (2M), pH, electrical conductivity and organic carbon by Walkley-Black (Carter 1993). Sand, silt and clay were determined by hydrometer (McKeague 1978). Acetate fluoride, ammonium acetate and 0.001 M calcium chloride extractions were used to determine phosphate phosphorus, potassium and sulfate-sulfur levels, respectively (McKeague 1978). Soil penetration resistance was measured using a CN-973 Soil Test proving ring cone penetrometer after planting in May 1998. Ten readings were taken in each block, at 2.5, 5, 7.5, 10 and 15 cm.

3.4.3.2 Vegetation

Survival of transplanted native forbs was monitored from May 15 to September 30 in 1998 and 1999. Monitoring was done every three weeks early in summer when plants were growing rapidly and every four weeks later in the season. Individual forb plants were marked after planting in 1998 using 4 by 5 cm numbered aluminum tags anchored to the ground with a 13 cm galvanized nail. At each inspection, every marked point was found, either manually or with a metal detector. At each inspection the following parameters were assessed for each individual plant. Plant health and vigor were recorded as either plant growth vigorous and healthy, plant yellowing or discolored, plant smaller or with fewer stems than other transplants or plant dead. Presence or

absence of buds, flowers and seeds were recorded. Plant growth form (rosette or elevated stem) and plant height and basal diameter were recorded in either late July or late August, depending on the approximate end of the growing season for the species. Height was determined by measuring the shoot from the base to the apex of the tallest stem. Basal diameter was the widest distance covered by all stems on the main plant and any stems associated with the plant, but not including basal leaves, measured at ground level. Transplants known to have set seed in 1998 were checked over summer 1999 for newly established seedlings.

Each transplanted species started spring growth, flowered, set seed and senesced at different times through the growing season. Therefore, no one date could be selected that gave maximum survival, bloom and seed set for each year. Instead, transplant survival, percent bloom and percent seed set were determined following completion of data collection for the year. For each species, the maximum number of plants found alive, blooming and with seed present at any inspection date between July and September was reported. Transplant height and diameter were measured in late July for long-fruited anemone (*Anemone cylindrica* A. Gray), harebell (*Campanula rotundifolia* L.) and three flowered avens (*Geum triflorum* Pursh) since these species mature early and often had senesced by August. Height and diameter of other species were measured in late August, near the end of their growing season.

The soil seed bank was assessed for invading species by identifying species growing in the unseeded borders around the plots and species in the plots that had not been included in the seed mix. Monitoring was done at three to four week intervals from May 15 to September 30 in 1998 and 1999. A reconnaissance vegetation survey was done in June and August of 1998. Species off-site were identified because they could contribute seed or vegetative propagules to the sites. The area was surveyed by walking the perimeter of each block, to a distance of 10 meters from the corner of the blocks, and identifying plant species present.

3.4.3.3 Climate

Meteorological stations located at the Edmonton International Airport, 5 km south of the Ellerslie site and the Elk Island National Park warden station, approximately 10 km

from the Oster Lake and Tawayik Lake sites, were used to record average monthly temperatures and total monthly precipitation. Climate data were obtained from Environment Canada.

3.4.3.4 Statistical Analyses

Statistical analyses were done using the General Linear Model (GLM) of SAS (SAS 1990). When examining averages of all transplanted forbs, the model used a split plot design to test effects of location, season of establishment, mowing and their interactions. Time was used as a repeated measure. Dependent variables included percent of forbs transplanted that survived, percent of live forbs that bloomed, percent of live forbs that set seed, height and diameter of live forbs. Individual forb species results were investigated using a split plot design to test effects of location, season of establishment and interactions between these treatments. Time was used as a repeated measure. Dependent variables were as above. Throughout, the Pdiff test was used for means separation in comparisons between the three locations and interactions with location. A probability of $P \leq 0.10$ was defined as significant. This research was exploratory in nature and a higher than normal significance level was chosen to indicate trends. Exact probabilities for the GLM tests are presented in the tables.

3.5 Results and Discussion

3.5.1 Climate

Average May through September (summer) temperatures at both Ellerslie and Elk Island were warmer than the 30 year average in 1997 (14.4 °C vs. 16.7 °C) and 1998 (14.7 °C vs. 16 °C) (Appendix A). In 1999, summer temperatures were cooler than the 30 year average, and averaged 12.4 °C at Ellerslie and 13.1 °C at Elk Island.

Total annual precipitation at Elk Island in the year prior to and two years following seeding (1997 to 1999) was below the 30 year average, and ranged from 494 mm in 1997 to 365 mm in 1999 (Appendix A). Total annual precipitation at Ellerslie over the same time period was generally higher than the 30 year average, and ranged

from 524 mm in 1997 to 434 mm in 1998. Sites at Elk Island received slightly more precipitation prior to fall planting in 1997 than those at Ellerslie. Both areas received similar amounts of precipitation over winter 1997. Ellerslie received more precipitation (418 mm) from April to September 1998 than did Elk Island. However, Ellerslie received less rain in spring and early summer than did Elk Island, more precipitation in winter 1998/1999 (140 mm vs. 99 mm) and more precipitation in summer 1999 (333 mm vs. 267 mm). Seeds germinating and growing at Elk Island sites from both the fall and spring planting treatments may have had slightly better moisture conditions for establishment than those at Ellerslie, but neither area was drought stressed during these years.

3.5.2 Soils

Soils at the three locations varied (Appendix A), although none presented serious limitations to plant growth. Soil at Tawayik Lake was predominately Uncas Loam, an Orthic Dark Gray Chernozem. Soil pH in surface horizons was slightly acidic (6.0 to 6.4) and became increasingly basic below. Soil at Oster Lake was predominately Cooking Lake Loam, an Orthic Gray Luvisol. Soil texture tended to be siltier, while texture at Tawayik Lake was sandier. Soil pH at Oster Lake was moderately acidic, ranging from 5.8 at the surface to 5.5 below. Soil at Ellerslie was Malmo Silty Clay Loam, an Eluviated Black Chernozem. Surface and subsoil pH was neutral, ranging from 6.7 to 6.8.

Soil density in the top 5 cm was low for all sites (0.3 Mpa) since the sites had been rototilled prior to sampling (Appendix A). Soil density remained low to 15 cm at Ellerslie (0.7 Mpa), but increased significantly below 5 cm at both Tawayik Lake (2.3 Mpa) and Oster Lake (2.1 Mpa). This may have restricted rooting depth of plants seeded at these two locations.

Surface soil salts at all three locations could present slight limitations to plant growth. Salt levels were lowest at Oster Lake and highest at Ellerslie (Appendix A). Very high organic carbon levels were present at the soil surface at Tawayik Lake (6.9%), but levels dropped sharply below 5 cm. High organic carbon levels were present in surface soils at Oster Lake (3.2%) and levels gradually decreased to very low (1.2%)

below. Ellerslie soil had high organic carbon levels throughout the upper profiles, ranging from 5.0% at the surface to 4.0% at 45 to 60 cm.

Soil nutrient levels varied considerably with location (Appendix A). Nitrogen, phosphorus and potassium levels were very high in the top 5 cm of soil at Tawayik Lake, but dropped rapidly to fairly low levels below this depth. At Oster Lake, surface soil had high levels of nitrogen and phosphorus, and levels of these nutrients tended to stay high in the top 60 cm of soil. Oster Lake had lower amounts of potassium and low levels of sulfur throughout the depth sampled. These sites had been disturbed two years prior to establishment of these plots and had been fallow for this time, allowing increased mineralization. Soil at Ellerslie had the lowest levels of soil nitrogen and phosphorus, but had higher levels of potassium and sulfur. Other researchers have found the number of native seedlings that establish decreases significantly as soil nitrogen levels increase (Biondini and Redente 1986, Wilson and Tilman 1991, Wilson and Gerry 1995).

3.5.3 Seed Bank and Invader Species

Many seed bank species were native or introduced weedy annuals (Appendix B). Lambsquarters (*Chenopodium album* L.) and maple-leaved goosefoot (*Chenopodium gigantospermum* Aellen) and other annuals were high at Oster and Tawayik Lakes. The most common annual at Ellerslie was canola (*Brassica campestris* L.). Canada thistle was the major perennial weed at Ellerslie and was present at Oster and Tawayik Lakes in small amounts. Perennial invaders were greatest at Tawayik Lake, with most cover from dandelions (*Taraxacum officinale* Weber), alsike clover (*Trifolium hybridum* L.) and red clover (*Trifolium pratense* L.). Perennial weeds were insignificant at Oster Lake until the second growing season when alsike and red clover increased on some plots.

Oster and Tawayik Lake sites were closely surrounded by native vegetation and had been disturbed only two years prior to seeding. Invasion from desirable native species was greater at these sites, with common yarrow and wild vetch (*Vicia americana* Muhl.) invading in high numbers (Appendix B). Ellerslie is a farmed research area, under cultivation for a number of years. Low invasion from desirable native forbs was expected, but a large number were found, with common yarrow and wild vetch most common.

The native seed lots used on these plots contained small amounts of seed from other plant species (Appendix B). Thus some species could have been introduced through the seed. Any of these species that established were identified.

3.5.4 Interactions Between Main Effects

Most interactions between treatment effects were insignificant and only main effects of location, season of seeding and mowing affected native forbs (Table 3.2).

3.5.5 Annual Weed Control by Mowing

Mowing during the first growing season did not impact the percent of transplants that survived and flowered in any treatment in either year (Table 3.3). Mowing significantly reduced the percent of transplants that set seed and reduced plant height the year the plots were mowed. By 1999, when no mowing occurred, there was no difference in transplant height or diameter between mowed and unmowed treatments.

Transplanted native forbs were able to compete with tall growing annual weeds, and mowing did not improve their survival. Before or between mowing, transplants produced flowers. However, mowing cut off flowering stalks on tall plants like Canada goldenrod (*Solidago canadensis* L.), common yarrow and smooth aster, preventing seed set. Since mowing did not kill the plants, plant growth, flowering and seed set the following year, when the plants were not cut, were the same on all treatments. Hesse and Salac (1972) found mowing could delay and extend the bloom period of wildflowers. In this experiment, the final mowing was too late in the season to see an extended bloom period. Since effects of mowing on individual species could not be examined, mowing may have extended the bloom period for shorter species. Mowing and removing apical dominance did not enhance tillering and vegetative spread on forbs as a whole, but did increase basal diameter of species with strongly creeping rhizomes like common yarrow, wild bergamot (*Monarda fistulosa* L.), smooth aster (*Aster laevis* L.) and Canada goldenrod.

3.5.6 Location

Location had no effect on transplant survival in the first growing season (Table 3.4). In the second growing season, 74 and 73% of the transplants were alive at Ellerslie and Oster Lake, respectively. At Tawayik Lake survival was significantly lower at 47%. First year survival at all three locations was not significantly different and ranged from 78 to 86%. High plant losses occurred over winter 1998/1999 at Tawayik Lake but not at Ellerslie and Oster Lake.

Significantly fewer wild blue flax (*Linum lewisii* Pursh) plants survived the first year at Tawayik Lake than at the other two sites (Table 3.4). In 1999, significantly fewer long-fruited anemone, harebell, wild blue flax, hoary puccoon (*Lithospermum canescens* (Michx.) Lehm.) and low goldenrod (*Solidago missouriensis* Nutt.) transplants survived at Tawayik Lake than at the other locations. Purple prairie clover (*Petelostemon purpureum* (Vent.) Rydb.) survival at Ellerslie was significantly greater than at either Oster or Tawayik Lake. In 1999, location had no effect on survival of common yarrow, smooth aster, three flowered avens and Canada goldenrod.

The Oster and Tawayik Lake locations may have had slightly better soil moisture conditions for transplant establishment. However, the Ellerslie location also received good precipitation during this time, so climate likely was not a major player in transplant establishment and survival. Soil conditions at the three locations varied, but these variations still fall within the range of adaptation for the native forb species used in this research (Appendix D). For example, common yarrow, Canada goldenrod and wild vetch are found in prairie, aspen parkland, boreal forest and montane ecosystems (Looman and Best 1994). Species like wild bergamot have a more limited range, but are still found throughout the aspen parkland and boreal forest.

Higher soil fertility levels at Tawayik and Oster Lake likely enhanced growth of annual weeds at the expense of native forb seedlings. Other researchers have found native plant establishment decreases with increased soil nitrogen levels (Biondini and Redente 1986, Wilson and Tilman 1991, Wilson and Gerry 1995).

Populations and growth of weeds and other invading plant species differed with location, and appeared to have the greatest impact on transplant survival. Oster and Tawayik Lake were disturbed more recently than Ellerslie so more seeds could be present

in the seedbank. Native plants were much closer to plots at Oster and Tawayik Lake than at Ellerslie and more native species would be expected to invade. Total plant density at Tawayik Lake averaged 330 plants m^{-2} in 1998 and 540 plants m^{-2} in 1999 (Pitchford 2000); unseeded species made up 300 and 500 plants m^{-2}, respectively. Total plant density at Oster Lake was 190 plants m^{-2} in 1998 and 180 plants m^{-2} in 1999; unseeded species made up 100 and 150 plants m^{-2}, respectively. Ellerslie had the lowest plant density in 1998 with 70 plants m^{-2}; 50 plants m^{-2} were unseeded. By 1999, plant density at Ellerslie was second highest at 390 plants m^{-2}, 360 of them unseeded.

Greater competition for sunlight, water and nutrients at Tawayik Lake may have resulted in greater transplant loss. In addition, dominant non-seeded plants appeared to vary with location. More perennial species, mainly dandelion and clovers, were observed at Tawayik Lake than the other locations. By the end of the first and through the second growing season, some replicates at Tawayik Lake had high cover from dandelions. The Oster Lake location, particularly in the first growing season, had cover mainly from tall growing annual weeds (maple-leaved goosefoot, lambsquarters and nettle (*Urtica dioica* L.)) with limited competition from low growing perennial weeds like alsike and red clover. After the second growing season, perennial weed cover increased, while annual cover was low. The Ellerslie plots had relatively low weed populations, particularly in the first growing season; most competition came from tall growing annual weeds, mainly canola. Competition in the second growing season at Ellerslie continued to come mainly from annual and biennial weeds. Heavy populations of low-growing perennial weeds reduced survival of transplants more than populations of annual weeds.

Even with the variation in competition among locations, first growing season survival of transplanted forbs did not differ. However, competition appeared to reduce overwinter transplant survival and plant growth and survival the following spring, since fewer forb transplants were alive at Tawayik Lake than at locations with less competition by the second growing season.

Common yarrow, smooth aster and Canada goldenrod are all tall growing, aggressive species with strongly creeping roots. These species competed well against weeds and other plants. Survival of blanket flower, three flowered avens and wild bergamot were also unaffected by location. Long-fruited anemone, harebell, hoary

puccoon and low goldenrod are low growing plants, with mainly basal leaves. These plants were less able to compete with low growing perennial weeds.

Native transplant survival in the first growing season ranged from 73 to 100% on alpine and subalpine sites in Alaska, despite hot, dry weather (Densmore and Holmes 1987). Survival rates of big sagebrush (*Artemisia tridentata* Nutt.) transplanted in spring were also high (Evans and Young 1990). At the end of the second growing season 96% of transplants remained alive and 89% were still alive after the third growing season. Water sedge (*Carex aquatilis* Wahl.) seedlings transplanted into high elevation, mined peat fen survived best in areas where good moisture was available or the water table was close to the surface (Cooper and MacDonald 2000). At the end of the first growing season 95% of spring planted transplants were alive, but only 67% were alive the following summer and survival was down to 50% by the second fall. Below ground competition from other plants suppresses growth of transplanted native seedlings (Gerry and Wilson 1995).

Survival of blanket flower (*Gaillardia aristata* Pursh), hoary puccoon, wild bergamot and purple prairie clover at Tawayik Lake was very low, especially on fall planted plots, resulting in less than one live transplant per replicate. As a result, Tawayik Lake data could not be used in comparisons of flowering, seed set, height or basal diameter for these species. Only data from Ellerslie and Oster Lake were included. Data from all three locations were used for other forbs.

In 1998, a significantly greater percent of forbs flowered at Ellerslie and Oster Lake than at Tawayik Lake (Table 3.5). Flowering increased in 1999 at all locations, but was still significantly lowest at Tawayik Lake. In the first growing season, location had no effect on flowering of common yarrow, long-fruited anemone, smooth aster, three flowered avens, hoary puccoon, wild bergamot, purple prairie clover and Canada goldenrod. The percent of harebell that flowered was greatest at Ellerslie and least at Tawayik Lake. This significant effect carried over into the following year. Flowering of blanket flower compared only plants at Ellerslie and at Oster Lake, with more flowering at Oster Lake than at Ellerslie in 1998. However, by 1999 this effect was no longer significant. Flowering of wild blue flax was also significantly affected by location in 1998, with more plants blooming at Oster and Tawayik Lake than at Ellerslie. There was

no difference in flowering of wild blue flax with location in 1999. Long-fruited anemone generally did not flower the first growing season. By the following summer, percent bloom varied significantly with location, with plants at Tawayik Lake less likely to bloom than plants at Oster Lake and Ellerslie. Location also affected flowering of smooth aster in 1999, with the greatest percent of plants blooming at Ellerslie and the least at Tawayik Lake. Three flowered avens bloomed sparingly the first year; by the second year the greatest percent flowered at Ellerslie and none flowered at Tawayik Lake.

The percent of plants that set seed at Ellerslie and Oster Lake was greater than at Tawayik Lake in 1998, but greater at Ellerslie than at Oster Lake and Tawayik Lake in 1999 (Table 3.6). Location affected seed set of harebell and wild blue flax in the first growing season. Harebell and smooth aster transplants at Tawayik Lake were significantly less likely to set seed in the second growing season than at other locations. The proportion of long-fruited anemone, three flowered avens and wild blue flax plants setting seed was greater at Ellerslie than at Oster Lake or Tawayik Lake. Location had no effect in either year on the percent of hoary puccoon, wild bergamot, purple prairie clover and Canada goldenrod plants that set seed. A high proportion of common yarrow and Canada goldenrod set seed at all locations. Hoary puccoon did not set seed at any location. Wild bergamot did not set seed in 1998, but some plants set seed in 1999. Purple prairie clover had few plants set seed in 1998, and none set seed in 1999. It flowered late in 1999, and seeds were killed by fall frost before maturation.

As competition from other plants increased, the percent of transplants that flowered and set seed was reduced. Production of viable seed early in the reclamation period may allow the number of native forbs on the site to increase over time. Earlier in the reclamation period, there are more opportunities for seeds to find a suitable niche for germination and growth, since ground cover and plant competition is usually relatively low. Blake (1935) found native forbs grown under cultivation, with low competition from other plants, set seed when they were one or two years old, while forbs growing with plant competition did not set seed until they were three or four years old.

In 1998, height of individual forb species was generally greater at Oster and Tawayik Lake and shortest at Ellerslie (Table 3.7). By 1999, forb height was greater at

Ellerslie, than at Oster Lake and shortest at Tawayik Lake. In the first growing season, long-fruited anemone was significantly shorter at Ellerslie, as was wild blue flax, hoary puccoon and Canada goldenrod. Purple prairie clover was significantly shorter at Ellerslie than at Oster Lake. By 1999, height of wild blue flax still differed significantly with location, with Oster Lake plants tallest, then Ellerslie and the shortest plants at Tawayik Lake. Hoary puccoon at Oster Lake was still significantly taller than at Ellerslie in 1999. However, by 1999, common yarrow was significantly taller at Ellerslie, as was smooth aster, purple prairie clover and Canada goldenrod. Height of harebell, three flowered avens and wild bergamot was not significantly different at any location.

Plant competition likely had the most influence on transplant height. Competition for nutrients and water, rather than competition for light, likely reduced plant height at Tawayik Lake since plants were shorter at this location. All transplants were taller in 1999 than in 1998, at all locations, as expected since plants were a year older.

Common yarrow, smooth aster, harebell, three flowered avens, wild bergamot, Canada goldenrod and low goldenrod all spread by rhizomes. Long-fruited anemone, blanket flower, wild blue flax, hoary puccoon and purple prairie clover are tap rooted so basal diameter results given here indicate only an increase in plant size for these species. By the end of the second growing season, transplants at Ellerslie spread significantly more than at the other two locations (Table 3.8). Spread at Oster Lake and Tawayik Lake was not significantly different. The Ellerslie location had better vegetative spread of smooth aster, harebell, three flowered avens, purple prairie clover, Canada goldenrod and low goldenrod. Blanket flower at Oster Lake spread significantly more than at Ellerslie. There was no difference in spread with location for common yarrow, wild blue flax and wild bergamot. Less plant competition from weeds and other species generally improved vegetative spread of transplanted forbs in this experiment.

3.5.7 Season of Planting

Season of planting significantly affected transplant survival in 1998 and 1999 (Table 3.9). Spring planting resulted in better transplant survival in the first growing season. These results carried over into the following year, although significantly more spring transplants died over winter than fall transplants. At the end of the first growing

season 68% of the fall transplants were alive, while 55% were still alive after two years. In the first year 97% of the spring transplants were alive, but only 79% remained alive by the second year. However, even with greater losses during winter 1998/1999, spring planting significantly increased transplant survival.

Spring planting increased establishment of long-fruited anemone, blanket flower, three flowered avens and purple prairie clover in both growing seasons (Table 3.9). Spring planting allowed better survival of hoary puccoon in 1998, but winter losses were high and by 1999 plant survival was not significantly different. Wild bergamot survival was better with spring planting in 1998, but by 1999 survival was significantly better if planted in fall. Common yarrow, smooth aster, harebell, wild blue flax and Canada goldenrod were not affected by season of planting. These species established very well, with over 80% of the plants surviving in the first year and over 65% in the second. Low goldenrod transplants also survived well on these plots. Long-fruited anemone, blanket flower, three flowered avens and wild bergamot survived well on spring planted plots, but poorly when planted in fall. Purple prairie clover generally survived the first growing season well, but had high death losses over winter, resulting in fewer plants by 1999. Hoary puccoon established well when spring planted, but over winter losses were high, especially on spring planted plots.

Fall planted seedlings had to rely on root reserves accumulated prior to planting for winter survival and spring regrowth. As a result, only the strongest transplants, with adequate root reserves, could survive and grow the following spring. Spring planted seedlings had the whole growing season to establish, considerably reducing stress. They had all summer to establish root reserves prior to winter. Competition for moisture and light removed the weakest plants at all locations, but many plants survived the first summer. However, more spring planted transplants were eliminated during their first winter. Thus death loss over winter 1998/1999 was greater for spring planted than fall planted plants.

Spring planting may have allowed transplants to establish more easily, resulting in stronger forbs during the first growing season. Spring seeded plots were cultivated prior to seeding which killed any winter annual and early germinating annual weeds and may have given transplants an advantage over weeds. Research on a variety of plant species

suggests early emergence gives an advantage over competitors in gaining resources (Ross and Harper 1972, Harper 1977, Weaver 1984, O'Donovan et al. 1985). However, the spring transplants had never survived a winter and some may not have been strong enough to survive, resulting in greater over-winter losses. Fall planted seedlings that could not survive the winter died prior to assessment in 1998.

Transplanting conditions were better in spring than fall. The soil was moister, looser and weather more conducive to placing each plant carefully. The fall planting crew had miserable weather and, especially at Oster Lake and Tawayik Lake, had trouble getting the seedlings deep enough into the cold, dry soil. Many seedlings observed in the spring were one quarter to one third out of the soil, and some of these did not contain live plants. Some seedlings also may have frost heaved, since there was no time for root growth out of the seedling prior to freeze up. No spring planted seedlings heaved over winter 1998/1999. Early spring moisture in spring 1998 was low. Desiccation of transplanted forbs may have resulted in high losses over the first winter, before the roots were able to establish. While spring and summer 1998 were also drier than average, there may have been enough precipitation to allow establishment of spring planted forbs.

LeBarron et al. (1938) found that tree transplant survival was significantly better with spring than fall planting. They attributed this partially to death losses from frost heaving and partially to the lack of opportunity for transplant roots to establish good soil contact, causing plants to suffer from a lack of water over the winter. They also found a significant soil type by planting season interaction in their research. Fall planting was much less detrimental on light soils than on heavy soils. In this research, the interaction between soil at the three locations and season of planting was not significant.

Marion and Alm (1986) found no difference in survival of red pine (*Pinus resinosa* Ait) transplants with spring or fall planting in Minnesota. However, trees planted in spring grew faster than fall planted trees in the first year. Mullin and Howard (1973) assessed planting of containerized trees after 10 years of growth, and found spring planting gave better survival of red pine and white pine (*Pinus strobus* L.) and resulted in taller trees than fall planting. Season of planting had no effect on white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill) BSP).

Season of planting did not affect percent of plants that flowered in 1998 or 1999

(Table 3.10). However, there were some species differences. In 1998, fall planted wild blue flax and low goldenrod were more likely to bloom than spring planted. Spring planted long-fruited anemone and purple prairie clover were significantly more likely to bloom in 1998. By 1999, the proportion of plants blooming was greater with spring than fall planting for long-fruited anemone, wild blue flax and Canada goldenrod.

In the first growing season, a high percent of transplanted species bloomed. More than 40% of common yarrow, smooth aster, harebell, blanket flower, wild blue flax, purple prairie clover and Canada goldenrod plants flowered the first year (Table 3.10). The percent of common yarrow, wild blue flax and Canada goldenrod plants flowering increased the next year, but fewer harebell and purple prairie clover plants flowered. The percent of smooth aster plants blooming was similar in both years. Flowering of blanket flower in 1999 increased slightly on the Ellerslie plots, but decreased on the Oster Lake plots. In the first growing season, less than 20% of the long-fruited anemone, three flowered avens and low goldenrod and no hoary puccoon and wild bergamot flowered. Flowering increased by the second year for long-fruited anemone, three flowered avens, wild bergamot and low goldenrod. Hoary puccoon did not bloom in either year.

Fall planting increased the proportion of transplants that set seed in 1998, but by the following growing season, there was no difference with season of planting (Table 3.11). Fall planted common yarrow, harebell, wild blue flax and low goldenrod were significantly more likely to set seed in the first growing season than if spring planted. However, by the following growing season, spring planting increased the percent of long-fruited anemone, smooth aster and low goldenrod plants that set seed. Other forb species were not affected by season of planting by the end of the second growing season.

Fall planting resulted in older, more mature wild blue flax and low goldenrod plants, which were more likely to bloom the first growing season. However, in general, even spring planted transplants bloomed in high proportions. Fall planted transplants were able to start growth earlier in spring 1998. Thus more of the fall transplants were mature enough to set seed the first growing season. By the end of the second growing season, this advantage was gone, and more spring planted forbs set seed than fall planted.

Over-wintering in the field, either as seeds or plants, causes vernalization in many species. Frischknecht (1951) found that fall planted grasses were more likely to flower

and set seed during the first growing season, while spring seeded grasses were more likely to remain vegetative. In theory, fall planted native forb transplants should have been more likely to bloom and set seed than the spring planted forbs due to vernalization.

Bohnen and Hanchek (1994) found flowering and seed set of purple prairie clover in a cultivated plot occurred one to two and a half weeks later than in similar wild plants on the prairie. In the first year, purple prairie clover seed on cultivated plots was killed by a hard frost before maturing, while seed set on the prairies was earlier and therefore undamaged. Purple prairie clover seed set in the second growing season of this experiment was also late and was damaged by frost before maturity.

Season of planting did not affect average height of transplants in 1998 or 1999 (Table 3.12). However, heights of some individual forb species were affected by planting season. Spring planting resulted in taller long-fruited anemone and smooth aster in both growing seasons. Most of the long-fruited anemone plants stayed as a rosette in 1998 on both spring and fall planted treatments. However, in 1999, significantly more spring planted anemones produced flower stalks than fall planted. Wild bergamot, Canada goldenrod and low goldenrod planted in fall were taller than spring planted in 1998. By 1999, wild bergamot plants were the same height regardless of planting season, fall planted Canada goldenrod continued to be significantly taller, and spring planted low goldenrod was taller than fall planted. Although there was no difference in height in 1998, by 1999 fall planted harebell and hoary puccoon were taller than spring planted. Height of blanket flower, three flowered avens and wild blue flax was not affected by season of planting.

Spring planted seedlings spread significantly more than fall planted seedlings after two growing seasons (Table 3.13). Spring planting significantly increased spread of common yarrow, long-fruited anemone, blanket flower, wild blue flax and Canada goldenrod. Fall planting resulted in larger diameter harebell plants.

3.6 Practical Applications

Transplanting native forb species is an alternative to seeding with expensive and often hard to find seed. Transplant survival varied with plant species; aggressive forb

species survived better than less competitive forb species. Introduction of native forbs by transplanting may speed their spread onto disturbed sites since seed is produced on site by transplanted forbs while space, nutrients and competition may be more conducive to seedling establishment. Many native forbs have rhizomes and not only colonize larger areas, but also provide ground cover and soil protection while other plants become established.

Spring planting generally was more successful than fall planting. Transplanting was easier to do in spring. Spring planting allowed seedlings to establish and accumulate root reserves, resulting in higher survival their first winter. Spring planted forbs spread over a larger area than fall planted forbs in the two growing seasons.

Weed control prior to planting native forbs, especially control of perennial weeds, should be a priority on reclamation sites. Increased competition from weeds reduced survival of transplanted forbs and reduced the vigor of those that did survive. Reducing weed populations prior to establishment will improve the stand. Mowing to control annual weeds during the establishment year had little effect on survival of transplanted native forbs or annual weed growth the following year. Mowing improved the visual appearance of the sites, but may have reduced long-term forb cover by reducing seed set.

Transplanting native forbs onto disturbed sites in the aspen parkland contributed quick, dramatic impact to the sites. The transplanted forbs grew and bloomed readily, even in the first year, and the flowers stood out from among the grasses and weeds. The showy native forbs added almost instant appeal and interest.

Transplanting increases the number of plants produced per PLS harvested, which is an advantage for wildflower species where limited quantities of seed are available, and those that are poorly adapted to establishing and surviving in the field. Later successional forb species may be well adapted to this type of production. In addition, the native seed production industry in Alberta is still small, and many forb species are currently only available as transplants. Transplanting may allow native forbs to be introduced to a reclamation site after weeds have been controlled and native grasses established. This may improve reclamation success and plant community development. However, transplanting native forbs also has some drawbacks. Seedlings may be more expensive to purchase than seed. As well, seedlings and equipment are bulky, and may

be more difficult to transport to remote locations.

3.7 Conclusions

Previous site management, in association with location within the aspen parkland ecoregion, determined plant competition on the site, which significantly affected native forb transplant survival, floral and vegetative reproduction and plant vigor in the first two growing seasons.

Spring planting improved native forb transplant survival, vegetative reproduction and plant vigor in the first two growing seasons. However, fall planted forbs were more likely to set seed in the first growing season.

Mowing in the first growing season to control annual weeds had no impact on native forb transplant survival and vegetative spread in the first two growing seasons. Mowing reduced forb height and the percent of plants that set seed in the first growing season, but had no effect by the second.

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Table 3.1 Species seeded and planted on research sites.

Common Name	Scientific Name	Transplants per plot	Seeding Rate ($g\ plot^{-1}$)
Northern wheatgrass	*Agropyron dasystachyum* (Hook) Scribn.[1]		12.287
Slender wheatgrass	*Agropyron trachycaulum* (Link) Malte var. *trachycaulum*		10.282
Blue grama grass	*Bouteloua gracilis* (HBK) Lag.		1.723
Plains rough fescue	*Festuca scabrella* Torr.		7.248
June grass	*Koeleria macrantha* (Ledeb.) J.A. Schultes f.		0.815
Green needle grass	*Stipa viridula* Trin.		6.347
Common yarrow	*Achillea millefolium* L.	2	
Long-fruited anemone	*Anemone cylindrica* A. Gray	9	
Smooth aster	*Aster laevis* L.	10	
Harebell	*Campanula rotundifolia* L.	11	
Blanket flower	*Gaillardia aristata* Pursh	4	
Three flowered avens	*Geum triflorum* Pursh	10	
Wild blue flax	*Linum lewisii* Pursh	7	
Hoary puccoon	*Lithospermum canescens* (Michx.) Lehm.	11	
Wild bergamot	*Monarda fistulosa* L.	8	
Purple prairie clover	*Petalostemon purpureum* (Vent.) Rydb.	11	
Canada goldenrod	*Solidago canadensis* L.	11	
Low goldenrod	*Solidago missouriensis* Nutt.	11	
Total transplanted		105	

[1] Plant names according to Moss 1992.

Table 3.2 Effect of interaction between location and season of planting on percent of native forbs that flowered and set seed and on plant height in 1998 and 1999.

					Ellerslie								Oster Lake			
					Fall				Spring				Fall			
					1998		1999		1998		1999		1998		1999	
		P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	% seed set	0.05	0.05	1.00	100 a[4]	0	100 a	0	38 b	25	100 a	0	42 b	12	100 a	0
	Height	0.70	0.56	0.06	57 a	19	84 a	4	41 a	4	82 a	11	51 a	5	66 b	8
Smooth aster	% seed set	0.26	0.10	0.01	70 a	48	95 a	10	24 b	21	96 a	6	28 b	14	81 a	1
Wild bergamot	% live	0.18	0.02	0.70	25 cd	20	22 cd	16	97 a	6	84 a	12	40 cd	4	28 cd	21
Purple prairie clover	% bloom	0.16	0.01	0.05	39 b	26	63 a	9	48 b	19	8 b	17	13 cd	18	1 b	1
	Height	0.12	0.01	0.01	39 b	5	72 a	8	32 c	2	64 b	8	37 b	4	35 d	8
Canada goldenrod	% seed set	0.03	0.04	0.52	72 a	18	98 a	4	33 bc	31	100 a	0	43 abc	10	96 a	6
Low goldenrod	% bloom	0.23	0.06	0.34	9 b	11	77 a	19	4 b	5	71 ab	15	32 a	6	64 ab	26
	% seed set	0.09	0.07	0.08	11 b	9	100 a	0	0 c	0	95 a	9	32 a	6	77 b	19
	Height	0.02	0.08	0.01	21 b	2	56 a	3	17 c	1	54 a	4	24 a	3	45 b	4
All forbs	% seed set	0.33	0.07	0.36	45 a	16	77 a	4	20 d	7	73 a	4	37 abc	13	58 cd	13

		Tawayik Lake											
		Spring				Fall				Spring			
		1998		1999		1998		1999		1998		1999	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	% seed set	0 c	0	100 a	0	67 b		100 a		50 b	71	100 a	0
	Height	57 a	27	75 b	4	80 a		502 c		67 a	51	74 ab	6
Smooth aster	% seed set	55 ab	7	95 a	7	55 ab	2	42 b	12	60 ab	14	94 a	8
Wild bergamot	% live	88 ab	0	75 ab	18	0 d	0	0 d	0	100 bc	0	13 bc	44
Purple prairie clover	% bloom	91 a	0	18 ab	10								
	Height	48 a	2	55 c	7								
Canada goldenrod	% seed set	80 a	7	96 a	6	23 c	32	90 a	14	69 ab	22	100 c	0
Low goldenrod	% bloom	0 b	0	71 ab	12	9 b	1	10 c	14	0 b	0	40 bc	4
	% seed set	0 c	0	84 ab	5	9 bc	1	11 d	2	0 c	0	40 c	4
	Height	17 c	1	44 c	3	19 bc	1	14 d	5	18 bc	2	32 c	1
All forbs	% seed set	34 bc	6	57 cd	9	28 cd	10	45 d	17	21 cd	7	52 cd	12

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between treatments in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between treatments in 1999 happened by chance.

[4] Within each year and across rows, means followed by the same letter are not significantly different ($P<0.10$).

Table 3.3 Effect of mowing on transplanted native forbs.

				1998		1998		1999		1999	
				Unmowed		Mowed		Unmowed		Mowed	
	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
% Survival	0.23	0.36	0.69	81	18	83	19	66	18	69	23
% Bloom	0.15	0.15	0.93	44	14	38	9	60	12	60	9
% Seed set	0.06	0.05	0.72	36	16	27	11	64	15	64	14
Height (cm)	0.01	0.01	0.96	34	6	28	4	49	7	50	10
Basal diameter (cm)			0.96					12	4	12	3

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.
[2] P 1998 value is the probability that the difference between mowing treatments in 1998 happened by chance.
[3] P 1999 value is the probability that the difference between mowing treatments in 1999 happened by chance.

Table 3.4 Effect of location on percent of transplanted native forbs that survived in 1998 and 1999.

					1998		1998		1998		1999		1999		1999	
					Ellerslie		Oster		Tawayik		Ellerslie		Oster		Tawayik	
Common name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.01	0.96	0.63	94	18	92	17	88	63	94	18	117	41	88	63
Long-fruited anemone	*Anemone cylindrica*	0.04	0.24	0.02	92	21	84	11	72	33	88 a	29	73 ab	23	47 b	37
Smooth aster	*Aster laevis*	0.06	0.34	0.42	68	37	93	9	100	24	65	37	98	4	75	37
Harebell	*Campanula rotundifolia*	0.05	0.81	0.02	94	11	98	5	86	42	89 a	11	77 a	13	39 b	24
Blanket flower	*Gaillardia aristata*	0.98	0.21	0.56	72	36	65	41	50	58	66	35	56	52	44	52
Three flowered avens	*Geum triflorum*	0.25	0.83	0.21	60	39	54	35	59	50	59	38	38	33	45	29
Wild blue flax	*Linum lewisii*	0.52	0.10	0.03	88 a[4]	18	100 a	0	50 b	41	82 a	26	100 a	0	36 b	36
Hoary puccoon	*Lithospermum canescens*	0.45	0.15	0.01	67	39	76	21	41	37	31 ab	24	49 a	10	5 b	9
Wild bergamot	*Monarda fistulosa*	0.33	0.40	0.11	61	41	64	27	50	58	53	36	51	32	22	36
Purple prairie clover	*Petalostemon purpureum*	0.02	0.35	0.01	78	21	86	18	73	29	65 a	25	37 b	32	11 b	17
Canada goldenrod	*Solidago canadensis*	0.24	0.99	0.99	107	49	107	9	109	22	106	49	109	7	109	22
Low goldenrod	*Solidago missouriensis*	0.27	0.21	0.09	97	12	93	9	84	20	95 a	14	91 ab	13	75 b	11
Total Present		0.01	0.52	0.03	82	20	86	11	78	21	74 a	18	73 a	12	47 b	18

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

[4] Within each year and across rows, means followed by the same letter are not significantly different ($P<0.10$).

Table 3.5 Effect of location on percent of transplanted native forbs that bloomed in 1998 and 1999.

					1998 Ellerslie		1998 Oster		1998 Tawayik[4]		1999 Ellerslie		1999 Oster		1999 Tawayik	
Common name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.54	0.56	0.17	94	18	88	25	100	0	100	0	100	0	100	0
Long-fruited anemone	*Anemone cylindrica*	0.01	0.57	0.01	3	5	0	0	3	6	62 a[5]	17	51 a	22	15 b	17
Smooth aster	*Aster laevis*	0.95	0.45	0.03	70	34	67	28	45	21	72 a	11	64 ab	19	43 b	37
Harebell	*Campanula rotundifolia*	0.99	0.01	0.01	95 a	7	76 ab	21	57 b	32	88 a	7	69 ab	34	47 b	23
Blanket flower	*Gaillardia aristata*	0.01	0.04	0.55	49 b	24	92 a	14			52	33	17	29		
Three flowered avens	*Geum triflorum*	0.29	0.92	0.07	13	35	3	6	0	0	53 a	31	19 ab	17	0 b	0
Wild blue flax	*Linum lewisii*	0.24	0.01	0.80	57 b	29	93 a	8	86 ab	25	87	16	93	8	83	29
Hoary puccoon	*Lithospermum canescens*	1.00	1.00	1.00	0	0	0	0	0	0	0	0	0	0	0	0
Wild bergamot	*Monarda fistulosa*	0.80	1.00	0.84	0	0	0	0			42	33	47	35		
Purple prairie clover	*Petalostemon purpureum*	0.04	0.64	0.12	43	22	52	46			22	20	9	12		
Canada goldenrod	*Solidago canadensis*	0.48	0.89	0.49	75	32	72	27	67	31	74 b	20	80 b	15	93 a	9
Low goldenrod	*Solidago missouriensis*	0.04	0.10	0.01	7 b	8	16 a	19	5 b	5	74 a	16	67 a	17	25 b	19
Total Present		0.20	0.01	0.08	43 a	12	46 a	9	31 b	7	64 a	7	60 a	5	50 b	13

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.
[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.
[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.
[4] Blank indicates not enough plants survived on each replicate to assess characteristic at this location.
[5] Within each year and across rows, means followed by the same letter are not significantly different ($P<0.10$).

Table 3.6 Effect of location on percent of transplanted native forbs that set seed in 1998 and 1999.

					1998 Ellerslie		1998 Oster		1998 Tawayik[4]		1999 Ellerslie		1999 Oster		1999 Tawayik	
Common name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.01	0.13	1.00	69	37	21	25	56	51	100	0	100	0	100	0
Long-fruited anemone	*Anemone cylindrica*	0.01	1.00	0.01	0	0	0	0	0	0	63 a[5]	19	26 b	24	9 b	19
Smooth aster	*Aster laevis*	0.16	0.83	0.02	50	43	41	18	58	9	96 a	8	88 a	9	68 b	32
Harebell	*Campanula rotundifolia*	0.01	0.01	0.01	90 a	11	76 a	25	37 b	23	91 a	8	31 b	17	0 c	0
Blanket flower	*Gaillardia aristata*	0.24	0.89	0.13	35	27	42	52			52	33	0	0		
Three flowered avens	*Geum triflorum*	0.05	1.00	0.01	0	0	0	0	0	0	59 a	31	4 a		0 a	0
Wild blue flax	*Linum lewisii*	0.23	0.02	0.99	40 b	47	79 a	18	57 ab	25	93	15	93	8	83	29
Hoary puccoon	*Lithospermum canescens*	1.00	1.00	1.00	0	0	0	0	0	0	0	0	0	0	0	0
Wild bergamot	*Monarda fistulosa*	0.70	1.00	0.57	0	0	0	0			46	28	37	28		
Purple prairie clover	*Petalostemon purpureum*	0.62	0.13	1.00	21	14	28	26			0	0	0	0		
Canada goldenrod	*Solidago canadensis*	0.54	0.69	0.42	53	31	61	22	46	35	99	3	96	8	95	10
Low goldenrod	*Solidago missouriensis*	0.01	0.04	0.01	6 b	8	16 a	19	5 b	5	98 a	6	81 b	12	26 c	17
Total Present		0.01	0.07	0.01	33 ab	18	35 a	10	25 b	9	75 a	5	58 b	10	49 b	14

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.
[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.
[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.
[4] Blank indicates not enough plants survived on each replicate to assess characteristic at this location.
[5] Within each year and across rows, means followed by the same letter are not significantly different (P<0.10).

Table 3.7 Effect of location on height (cm) of transplanted native forbs in 1998 and 1999.

Common name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	1998 Ellerslie Mean	S.D.	1998 Oster[4] Mean	S.D.	1998 Tawayik Mean	S.D.	1999 Ellerslie Mean	S.D.	1999 Oster Mean	S.D.	1999 Tawayik Mean	S.D.
Common yarrow	*Achillea millefolium*	0.05	0.40	0.03	49	15	54	16	72	16	83 a[5]	8	70 b	8	66 c	14
Long-fruited anemone	*Anemone cylindrica*	0.01	0.04	0.15	8 b	2	14 a	3	14 a	5	33	8	25	14	17	11
Smooth aster	*Aster laevis*	0.10	0.95	0.07	33	14	32	18	32	15	57 a	10	53 a	10	38 b	16
Harebell	*Campanula rotundifolia*	0.09	0.26	0.40	32	8	34	6	38	8	54	6	50	4	48	10
Blanket flower	*Gaillardia aristata*	NA	NA	NA	40	14					49	13				
Three flowered avens	*Geum triflorum*	0.23	0.51	0.11	8	1	8	1	9	3	27	10	21	10	18	3
Wild blue flax	*Linum lewisii*	0.01	0.03	0.04	38 b	13	54 a	5	47 ab	4	68 ab	16	80 a	7	47 b	6
Hoary puccoon	*Lithospermum canescens*	0.41	0.08	0.07	9 b	4	14 a	7			20 b	8	28 a	6		
Wild bergamot	*Monarda fistulosa*	0.68	0.17	0.87	19	6	22	5			39	15	40	8		
Purple prairie clover	*Petalostemon purpureum*	0.01	0.09	0.02	35 b	5	41 a	6			68 a	8	45 b	13		
Canada goldenrod	*Solidago canadensis*	0.01	0.04	0.06	52 b	11	62 a	2	61 a	4	85 a	8	83 ab	3	75 b	6
Low goldenrod	*Solidago missouriensis*	0.01	0.28	0.01	19	2	20	5	19	1	55 a	3	44 b	3	23 c	11
Total Present		0.01	0.21	0.01	29	6	34	7	32	5	54 a	5	50 b	3	38 c	8

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between locations in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

[4] Blank indicates not enough plants survived on each replicate to assess characteristic at this location.

[5] Within each year and across rows, means followed by the same letter are not significantly different ($P<0.10$).

Table 3.8 Effect of location on basal diameter (cm) of transplanted native forbs in 1999.

Common name	Scientific Name	P 1999[1]	1999 Ellerslie Mean	S.D.	1999 Oster Mean	S.D.	1999 Tawayik[2] Mean	S.D.
Common yarrow	*Achillea millefolium*	0.33	34	12	23	12	30	21
Long-fruited anemone	*Anemone cylindrica*	0.13	2 a[3]	1	2 a	1	1 b	0
Smooth aster	*Aster laevis*	0.01	14 a	3	9 ab	5	5 b	5
Harebell	*Campanula rotundifolia*	0.01	11 a	3	6 b	3	3 c	2
Blanket flower	*Gaillardia aristata*	0.03	10 b	5	21 a	1		
Three flowered avens	*Geum triflorum*	0.11	4	1	4	1	3	1
Wild blue flax	*Linum lewisii*	0.45	10	5	10	4	5	2
Hoary puccoon	*Lithospermum canescens*	0.03	3 a	1	2 b	1		
Wild bergamot	*Monarda fistulosa*	0.60	15	6	11	4		
Purple prairie clover	*Petalostemon purpureum*	0.01	5 a	1	3 a	2		
Canada goldenrod	*Solidago canadensis*	0.01	49 a	19	30 b	3	25 b	6
Low goldenrod	*Solidago missouriensis*	0.01	23 a	5	11 b	3	6 b	4
Total Present		0.01	15 a	2	10 b	2	8 b	3

[1] P 1999 value is the probability that the difference between locations in 1999 happened by chance.

[2] Blank indicates not enough plants survived on each replicate to assess characteristic at this location.

[3] Within each year and across rows, means followed by the same letter are not significantly different (P<0.10).

Table 3.9 Effect of planting season on percent of transplanted native forbs that survived in 1998 and 1999.

					1998 Fall		1998 Spring		1999 Fall		1999 Spring	
Common name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.01	0.66	0.74	88	44	96	12	94	50	102	23
Long-fruited anemone	*Anemone cylindrica*	0.07	0.10	0.01	71	23	99	13	55	34	93	17
Smooth aster	*Aster laevis*	0.36	0.43	0.21	76	28	88	35	66	31	85	35
Harebell	*Campanula rotundifolia*	0.81	0.97	0.75	93	29	93	9	72	26	75	27
Blanket flower	*Gaillardia aristata*	0.76	0.01	0.01	29	28	100	0	25	30	91	19
Three flowered avens	*Geum triflorum*	0.22	0.01	0.01	27	20	90	21	24	18	76	24
Wild blue flax	*Linum lewisii*	0.55	0.26	0.19	75	23	88	35	66	34	84	35
Hoary puccoon	*Lithospermum canescens*	0.01	0.01	0.69	37	32	89	11	25	26	32	23
Wild bergamot	*Monarda fistulosa*	0.09	0.01	0.01	23	20	95	6	18	72	17	27
Purple prairie clover	*Petalostemon purpureum*	0.84	0.01	0.01	61	15	97	4	27	23	61	34
Canada goldenrod	*Solidago canadensis*	0.17	0.25	0.31	97	7	118	48	98	8	117	49
Low goldenrod	*Solidago missouriensis*	0.56	0.11	0.15	99	6	86	17	94	10	84	18
Total Present		0.02	0.01	0.01	68	15	97	4	55	18	79	15

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between planting seasons in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between planting seasons in 1999 happened by chance.

Table 3.10 Effect of planting season on percent of transplanted native forbs that bloomed in 1998 and 1999.

					1998 Fall		1998 Spring		1999 Fall		1999 Spring	
Common name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Common yarrow	*Achillea millefolium*	0.17	0.17	1.00	100	0	88	23	100	0	100	0
Long-fruited anemone	*Anemone cylindrica*	0.02	0.08	0.01	0	0	4	6	34	26	60	20
Smooth aster	*Aster laevis*	0.98	0.18	0.20	54	37	71	16	55	29	71	15
Harebell	*Campanula rotundifolia*	0.98	0.37	0.44	86	22	76	26	78	17	68	32
Blanket flower	*Gaillardia aristata*	0.40	0.73	0.20	67	24	58	34	54	42	33	30
Three flowered avens	*Geum triflorum*	0.21	0.36	0.17	17	41	1	4	29	40	39	30
Wild blue flax	*Linum lewisii*	0.01	0.03	0.03	88	21	54	26	80	18	98	6
Hoary puccoon	*Lithospermum canescens*	1.00	1.00	1.00	0	0	0	0	0	0	0	0
Wild bergamot	*Monarda fistulosa*	0.78	1.00	0.78	0	0	0	0	40	43	47	23
Purple prairie clover	*Petalostemon purpureum*	0.01	0.01	0.57	30	26	62	27	24	20	12	15
Canada goldenrod	*Solidago canadensis*	0.64	0.96	0.01	72	28	73	31	75	18	85	17
Low goldenrod	*Solidago missouriensis*	0.06	0.01	0.33	15	13	2	4	57	34	63	18
Total Present		0.15	0.25	0.56	44	14	38	9	60	11	60	10

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between planting seasons in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between planting seasons in 1999 happened by chance.

Table 3.11 Effect of planting season on percent of transplanted native forbs that set seed in 1998 and 1999.

Common name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	1998 Fall Mean	S.D.	1998 Spring Mean	S.D.	1999 Fall Mean	S.D.	1999 Spring Mean	S.D.
Common yarrow	*Achillea millefolium*	0.08	0.08	1.00	79	28	31	37	100	0	100	0
Long-fruited anemone	*Anemone cylindrica*	0.04	1.00	0.04	0	0	0	0	30	32	50	28
Smooth aster	*Aster laevis*	0.14	0.74	0.01	56	37	43	23	78	25	95	6
Harebell	*Campanula rotundifolia*	0.04	0.03	0.79	83	20	64	33	54	42	53	45
Blanket flower	*Gaillardia aristata*	1.00	0.58	0.20	54	42	25	22	54	42	25	32
Three flowered avens	*Geum triflorum*	0.52	1.00	0.52	0	0	0	0	33	41	35	37
Wild blue flax	*Linum lewisii*	0.01	0.01	0.16	79	21	24	35	85	20	98	6
Hoary puccoon	*Lithospermum canescens*	1.00	1.00	1.00	0	0	0	0	0	0	0	0
Wild bergamot	*Monarda fistulosa*	0.60	1.00	0.60	0	0	0	0	50	37	37	15
Purple prairie clover	*Petalostemon purpureum*	0.21	0.21	1.00	15	16	32	16	0	0	0	0
Canada goldenrod	*Solidago canadensis*	0.34	0.26	0.28	52	28	54	31	95	7	99	3
Low goldenrod	*Solidago missouriensis*	0.01	0.01	0.09	16	12	0	0	72	40	79	25
Total Present		0.03	0.01	0.90	39	15	24	9	64	17	64	12

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between planting seasons in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between planting seasons in 1999 happened by chance.

Table 3.12 Effect of planting season on height (cm) of transplanted native forbs in 1998 and 1999.

Common name	Scientific Name	P Time[1]	P 1998[2]	P 1999[3]	1998 Fall Mean	S.D.	1998 Spring Mean	S.D.	1999 Fall Mean	S.D.	1999 Spring Mean	S.D.
Common yarrow	*Achillea millefolium*	0.03	0.81	0.19	58	17	51	18	74	15	78	9
Long-fruited anemone	*Anemone cylindrica*	0.01	0.02	0.01	9	4	13	4	21	11	34	10
Smooth aster	*Aster laevis*	0.45	0.03	0.02	24	14	43	6	45	13	58	10
Harebell	*Campanula rotundifolia*	0.42	0.32	0.01	36	6	32	9	56	7	48	5
Blanket flower	*Gaillardia aristata*	0.52	0.69	0.96	38	19	42	12	51	3	47	18
Three flowered avens	*Geum triflorum*	0.20	0.29	0.16	7	2	9	1	17	8	28	8
Wild blue flax	*Linum lewisii*	0.07	0.19	0.77	48	8	40	14	67	15	67	19
Hoary puccoon	*Lithospermum canescens*	0.45	0.10	0.02	15	6	8	3	29	5	18	7
Wild bergamot	*Monarda fistulosa*	0.97	0.01	0.34	25	3	17	5	42	16	38	12
Purple prairie clover	*Petalostemon purpureum*	0.12	0.68	0.06	38	4	36	8	59	20	61	8
Canada goldenrod	*Solidago canadensis*	0.39	0.03	0.06	62	6	52	9	85	9	79	4
Low goldenrod	*Solidago missouriensis*	0.01	0.01	0.02	21	3	17	1	42	19	46	10
Total Present		0.99	0.77	0.78	32	6	30	6	50	10	48	7

[1] P Time value is the probability that the change in results between 1998 and 1999 happened by chance.

[2] P 1998 value is the probability that the difference between planting seasons in 1998 happened by chance.

[3] P 1999 value is the probability that the difference between planting seasons in 1999 happened by chance.

Table 3.13 Effect of planting season on basal diameter (cm) of transplanted native forbs in 1999.

Common name	Scientific Name	P 1999[1]	1999 Fall Mean	S.D.	1999 Spring Mean	S.D.
Common yarrow	*Achillea millefolium*	0.06	22	11	37	13
Long-fruited anemone	*Anemone cylindrica*	0.05	2	1	2	1
Smooth aster	*Aster laevis*	0.15	9	7	12	4
Harebell	*Campanula rotundifolia*	0.01	9	4	5	4
Blanket flower	*Gaillardia aristata*	0.01	5	3	16	5
Three flowered avens	*Geum triflorum*	0.12	3	1	4	1
Wild blue flax	*Linum lewisii*	0.07	7	3	11	5
Hoary puccoon	*Lithospermum canescens*	0.40	3	2	2	1
Wild bergamot	*Monarda fistulosa*	0.83	13	8	14	4
Purple prairie clover	*Petalostemon purpureum*	0.15	4	2	5	1
Canada goldenrod	*Solidago canadensis*	0.05	30	9	46	21
Low goldenrod	*Solidago missouriensis*	0.28	14	9	17	8
Total Present		0.01	11	4	13	3

[1] P 1999 value is the probability that the difference between planting seasons in 1999 happened by chance.

CHAPTER 4 ESTABLISHMENT OF NATIVE FORBS ON DISTURBED ASPEN PARKLAND

4.1 ESTABLISHMENT OF NATIVE FORBS BY SEEDING AND TRANSPLANTING

Native forbs have the reputation of being hard to establish. However, this research found that native forbs could be established successfully in the aspen parkland ecoregion of Alberta by either broadcast seeding or by transplanting. Forbs are an important component of native plant communities and should be considered when deciding on a seed mix. Appropriate management greatly improved success in native forb establishment. Aggressive native forb species such as common yarrow (*Achillea millefolium* L.), wild vetch (*Vicia americana* Muhl.), and possibly other species such as pasture sage (*Artemisia frigida* Willd.), fireweed (*Epilobium angustifolium* L.), golden corydalis (*Corydalis aurea* Willd.) and Bicknell's geranium (*Geranium bicknellii* Britt.) may invade disturbances without human intervention, provided there is a source of seed or other plant propagules on or near the site. However, invasion of many other native forbs will take many years. With appropriate management and good quality forb seed or plants, native forbs can be readily introduced to disturbed sites during the reclamation process.

Broadcast seeding native forbs at a rate of 60 pure live seeds (PLS) m^{-2} generated forb populations of 1.3 to 2.3 plants m^{-2} within two years (Table 4.1). Overall, spring seeding allowed the best establishment of the ten native forb species studied in this research, although there were some species differences. One forb species established better when seeded in the fall, four established best when seeded in the spring, and five species established at similar rates from both spring and fall seeding. Most native forb species had some establishment when seeded in the fall. If fall seeding is the best management option for the disturbed site, a higher forb seeding rate may compensate for reduced establishment.

Planting forbs at a rate of one plant m^{-2} resulted in forb populations of 0.5 to 0.7 plants m^{-2} after two years (Table 4.1). Spring was also the best season to successfully

establish transplanted native forbs. Planting conditions were better in the spring than in fall, and fewer plants frost heaved or died over the winter.

In the first growing season, annual weed growth was heavy on all plots. Mowing the plots to control annual weed growth reduced establishment of seeded native forbs in the first growing season, but had no effect by the end of the second growing season. Neither annual weed growth nor mowing affected survival of transplanted native forbs. By the second year, growth of annual weeds was much lower on the plots and there did not appear to be any difference in annual weed populations between areas that had been mowed and those that had not. Mowing annual weeds did not improve survival of native forb seedlings or transplants, and did not appear to change weed populations in the following year.

Competition from low-growing perennial weeds like dandelions (*Taraxacum officinale* Weber) and clovers (*Trifolium* spp.) reduced establishment and survival of native forb seedlings and transplants. Where low levels of these weeds were present, more native plants became established (Table 4.1). Where perennial weed numbers were high, fewer native forb seedlings and transplants were able to survive. Controlling perennial weeds prior to seeding or planting native forbs will greatly improve forb survival.

4.2 Establishment of Native Forbs on Disturbed Aspen Parkland – Best Management Practices

4.2.1 Seeding Native Forbs

Weed populations should be reduced prior to seeding. Control of perennial weeds is important and may require the use of herbicides and or tillage over several years. The forb seed mix should be broadcast onto a firm, roughened seedbed in spring. Forbs can also be broadcast seeded in fall, but establishment rates will be lower. Doubling the amount of forb seed used may compensate for seed losses over winter. Seeding rates for common yarrow, wild vetch, and other invasive native forbs can be reduced if the disturbed area is near undisturbed native vegetation or is likely to contain seeds from

these species. These more aggressive native species will colonize such sites more readily than other forb species. Leave annual weeds to shelter seedlings. Growth of annual weeds in the first growing season may be less detrimental to native forb seedlings than mowing to control weeds. In the first year, native forb seedlings are generally small and inconspicuous. More will flower and are readily visible by the second growing season. The number of native forbs present will increase over at least two years.

4.2.2 Transplanting Native Forbs

Weed populations should be reduced prior to seeding. Control of perennial weeds is important and may require the use of herbicides and or tillage over several years. Plant nursery grown transplants in spring for easiest handling and best plant survival. Leave annual weeds to shelter transplants. Native forb transplants are able to compete with annual weeds. Many transplanted forbs will flower and produce seed in the first growing season.

4.3 Questions for Future Research

The use of native plant species, particularly native forbs, for reclamation in Alberta is still a very new practice. This research provided some information about establishment of native forb species on disturbances in the aspen parkland ecoregion, but it also emphasized the need for further research.

One important question not answered by this research is how many native forbs are enough in a plant community? Does this change as the community develops? Future research could assess the impact of different native forb seeding and/or transplanting rates on plant community development. Information on exactly how native forbs affect plant communities is limited and no research has assessed how many forb plants and different species are needed in an area to effectively shape future plant communities.

Competition from weedy plant species affects establishment and survival of native plants. Adding native forbs limits opportunities for chemical weed control. Is the negative impact of weedy species on native plant community development greater than the positive impact of native forb presence early in the reclamation period? Future

research could compare native plant community development when forbs are introduced early in the reclamation period, to establishment of a weed free, healthy native grass stand initially and then introducing native forbs.

Can native forbs be successfully introduced into native grass stands that have had some time to become established on disturbances? Future research could investigate methods of introducing native forbs into areas where native grass mixtures have previously been established. Comparing transplanting to seeding into these plant communities would determine whether forbs can be introduced at a later time, and what the best method would be, increasing early site management options.

Finally, the future use of native plant species depends upon development of a reliable, economical supply of seed and plants for native species. Further research into growing requirements, seed production and management of native forb and grass species is needed to ensure that native seed is available for use when it is needed.

Table 4.1 Effect of season of planting and weed population on number of native forb plants m^{-2} established by seeding and transplanting in the first and second growing seasons.

	Seeded at 60 PLS m^{-2}		Transplanted at 1 plant m^{-2}	
	Live forbs m^{-2}		Live forbs m^{-2}	
	1998	1999	1998	1999
Planting season				
Spring	2.0	2.2	0.9	0.7
Fall	0.9	1.2	0.6	0.5
Weed population				
Very high perennial weed cover	1.4	1.3	0.7	0.4
Moderate to high perennial weed cover	1.4	1.5	0.8	0.7
Low perennial weed cover	1.5	2.3	0.8	0.7

APPENDIX A DETAILED SITE INFORMATION

Table A.1 History of research sites at Ellerslie and Elk Island National Park.

	Ellerslie[1]			Elk Island National Park[2]		
Year	Crop	Fertilizer (Rate, Grade)	Weed Control	Crop	Fertilizer	Weed Control
1997	Canola	None	Ethalfluralin	Fallow	None	Glyphosate, cultivation
1996	Fallow	None	Cultivation	Fallow	None	None
1995	Wheat	45 kg ha^{-1}, 11-51-0	Dicamba	Native seed research	None	Cultivation
1994	Canola	56 kg ha^{-1}, 11-51-0	Ethalfluralin	Native pasture	None	None
1993	Red clover*	None (*inoculated)	None	Native pasture	None	None
1992	Wheat	45 kg ha^{-1}, 11-51-0	Dicamba			
1991	Fallow	None	Cultivation			
1990	Wheat	30 kg ha^{-1}, 11-51-0	Dicamba			
1989	Fallow	None	Cultivation			
1988	Hay	None	Cultivation			
Pre 1988	Hay	None	Cultivation			

[1] Pitchford 1998

[2] Bush 1998

Table A.2 Average soil chemical and physical properties of research sites.

	Sample Depth	pH	EC (Umhos)	NO_3-N (ppm)	NH_4-N (ppm)	% OC	Particle Size % Sand	% Silt	% Clay	Phosphate (mg kg^{-1})	Potassium (mg kg^{-1})	Sulphate (mg kg^{-1})	Sample Depth	Penetration Resistance (Mpa)
Tawayik Lake	0-5 cm	6.0	393.5	58.4	10.1	6.9	44.8	40.8	14.4	31	363	19.8	2.5 cm	0.3
	5-15 cm	6.4	165.0	19.9	4.5	2.1	46.4	39.7	14.0	10	99	9.8	5.0 cm	0.6
	15-30 cm	6.8	177.4	18.4	4.4	2.1	45.6	37.2	17.3	13	124	14.0	7.5 cm	1.5
	30-45 cm	7.4	233.5	14.5	5.1	1.5	45.4	24.0	30.6				10.0 cm	2.3
	45-60 cm	7.8	326.7	8.0	3.3	0.9	47.0	21.4	31.6				15.0 cm	1.8
Oster Lake	0-5 cm	5.8	233.5	38.0	6.4	3.2	33.1	49.2	17.7	20	286	5.1	2.5 cm	0.3
	5-15 cm	6.1	204.6	33.9	5.6	2.4	31.1	49.9	19.0	16	234	4.2	5.0 cm	0.6
	15-30 cm	6.2	157.6	33.1	6.6	2.2	30.1	49.7	20.2	15	217	4.2	7.5 cm	1.4
	30-45 cm	5.5	148.5	20.5	5.4	1.2	29.3	34.8	36.0				10.0 cm	2.0
	45-60 cm	5.5	148.5	19.0	5.7	1.2	29.3	37.1	33.7				15.0 cm	2.1
Ellerslie	0-5 cm	6.7	390.6	23.1	5.0	5.8	21.7	44.2	34.0	11	287	70.3	2.5 cm	0.3
	5-15 cm	6.7	430.7	28.9	5.0	5.6	26.9	39.4	33.7	9	256	79.0	5.0 cm	0.4
	15-30 cm	6.7	380.3	22.0	4.6	4.3	22.6	43.0	34.4	8	230	82.5	7.5 cm	0.5
	30-45 cm	6.8	329.6	13.1	3.9	2.7	21.1	39.4	39.5				10.0 cm	0.5
	45-60 cm	6.7	353.1	7.3	4.0	1.6	18.6	34.4	47.0				15.0 cm	0.7

Figure A.1 Mean monthly temperature at Elk Island National Park meteorological station for 1997, 1998, 1999 and 30 year average (°C).

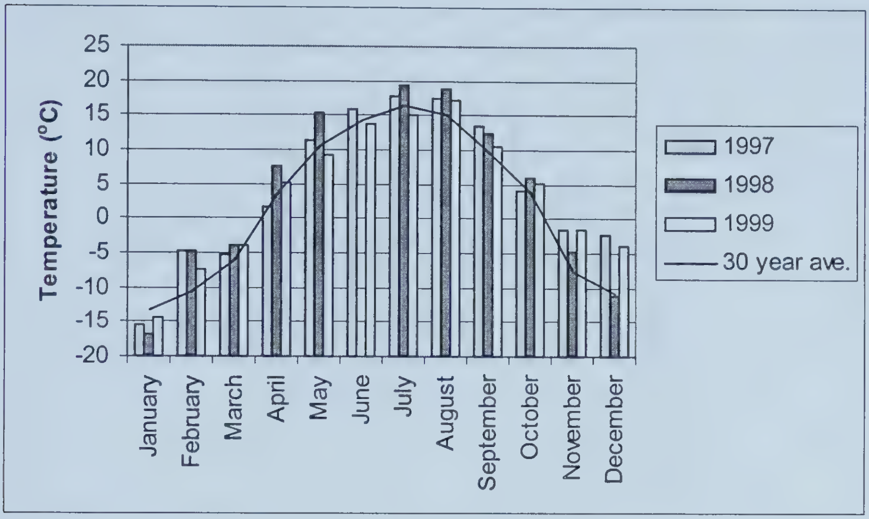


Figure A.2 Monthly precipitation for Elk Island National Park meteorological station for 1997, 1998, 1999 and 30 year average (mm).

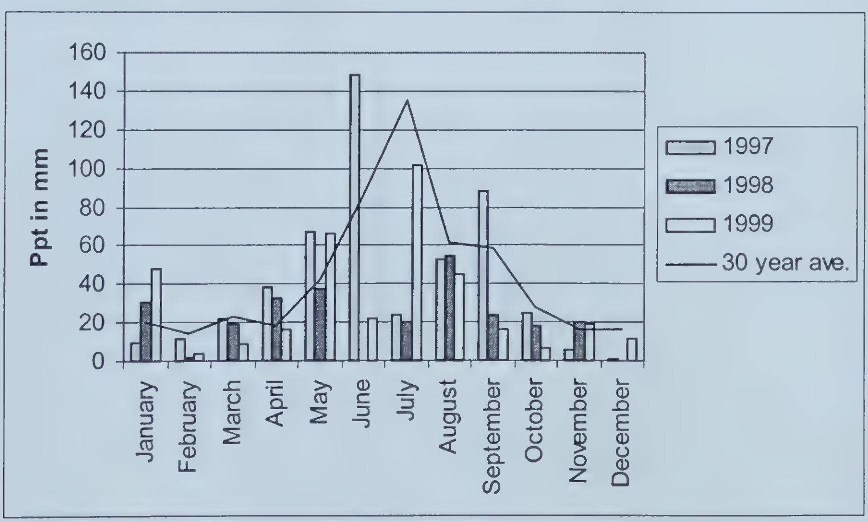


Figure A.3 Mean monthly temperature at Edmonton International Airport meteorological station for 1997, 1998, 1999 and 30 year average (^oC).

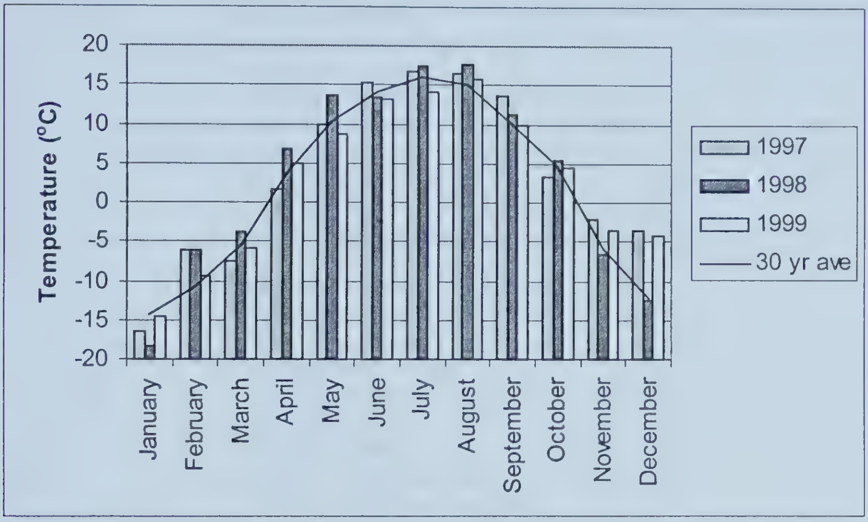
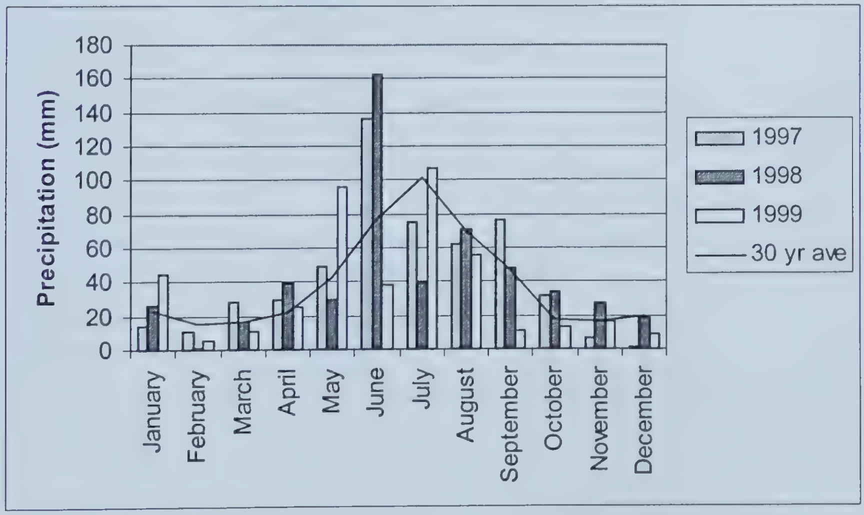


Figure A.4 Monthly precipitation for Edmonton International Airport meteorological station for 1997, 1998, 1999 and 30 year average (mm).



APPENDIX B UNSEEDED SPECIES ON RESEARCH SITES

Table B.1 Plant species found on research sites growing from seed bank.

Common Name	Scientific Name	Tawayik Lake	Oster Lake	Ellerslie
Common yarrow	*Achillea millefolium* L.	P	P	P
Quackgrass	*Agropyron repens* (L.) Beauv.			P
Prostrate pigweed	*Amaranthus graecizans* L.	P		P
Redroot pigweed	*Amaranthus retroflexus* L.		P	
Biennial wormwood	*Artemisia biennis* Willd.		P	
Lindley's aster	*Aster ciliolatus* Lindl.		P	
Smooth aster	*Aster laevis* L.		P	
Wild oat	*Avena fatua* L.			P
Yellow avens	*Avens macrophyllum* Jacq.		P	P
Canola	*Brassica campestris* L.	P	P	P
Wild mustard	*Brassica hirta* Moench		P	
Mustard	*Brassica* spp.	P	P	
Smooth brome grass	*Bromus inermis* Leyss.	P	P	
Japanese brome	*Bromus japonicus* Thunb.		P	
Shepherd's Purse	*Capsella bursa-pastoris* (L.) Medic.	P	P	P
Wetland sedges	*Carex* spp.		P	
Lambsquarters	*Chenopodium album* L.	P	P	P
Strawberry blite	*Chenopodium capitatum* (L.) Aschers.	P		P
Maple-leaved goosefoot	*Chenopodium gigantospermum* Aellen	P	P	P
Canada thistle	*Cirsium arvense* (L.) Scop.	P	P	P
Golden corydalis	*Corydalis aurea* Willd.	P	P	P
Narrow-leaved hawksbeard	*Crepis tectorum* L.	P	P	P
Flixweed	*Descurainia sophia* (L.) Webb	P	P	P
Yellow whitlow grass	*Draba nemorosa* L.	P		
American dragonhead	*Dracocephaum pariflorum* Nutt.		P	P
Fireweed	*Epilobium angustifolium* L.	P	P	
Purple-leaved willow herb	*Epilobium ciliatum* Raf.	P	P	P
Epilobium spp.	*Epilobium* spp.	P	P	P
Horsetail	*Equisetum* spp.		P	P
Philadelphia fleabane	*Erigeron philadelphicus* L.	P		P
Dog mustard	*Erucastrum gallicum* (Willd.) Schulz	P		
Wormseed mustard	*Erysimum cheirahthoides* L.			P
Wild strawberry	*Fragaria virginiana* Duchesne	P	P	
Hempnettle	*Galeopsis tetrahit* L.	P	P	P
Bicknell's geranium	*Geranium bicknellii* Britt.	P	P	
Yellow avens	*Geum aleppicum* Jacq.	P	P	
Prickly lettuce	*Lactuca serriola* L.		P	
Common peppergrass	*Lepidium densiflorum* Schrad.			P
Pineappleweed	*Matricaria matricariodes* (Less.) Porter	P	P	P
Alfalfa	*Medicago sativa* L.			P
Yellow sweetclover	*Melilotus officinalis* (L.) Lam.	P	P	P
Yellow evening primrose	*Oenothera biennis* L.	P	P	
Timothy	*Phleum pratense* L.	P	P	

Table B.1 Plant species found on research sites growing from seed bank (continued).

Common Name	Scientific Name	Tawayik Lake	Oster Lake	Ellerslie
Plantain	*Plantago major* L.	P	P	P
Annual bluegrass	*Poa annua* L.	P		
Bluegrass	*Poa* spp.	P		P
Prostrate knotweed	*Polygonum aviculare* Greene	P	P	
Wild buckwheat	*Polygonum convolvulus* L.	P	P	P
Green smartweed	*Polygonum lapathifolium* L.	P		P
Lady's-thumb	*Polygonum persicaria* L.	P		P
Balsam poplar	*Populus balsamifera* L.		P	
Purslane	*Portulaca oleracea* L.			P
Rough cinquefoil	*Potentilla norvegica* L.	P	P	
Wild rose	*Rosa woodsii* Lindl.		P	
Wild raspberry	*Rubus idaeus* L.	P	P	
Common groundsel	*Senecio vulgaris* L.	P		P
Night-flowering catchfly	*Silene noctiflora* L.	P	P	
White cockle	*Silene pratensis* (Rafn) Godron & Gren.			P
Blue eyed grass	*Sisyrinchium montanum* Greene	P	P	P
Canada goldenrod	*Solidago canadensis* L.	P	P	
Perennial sow thistle	*Sonchus arvensis* L.		P	P
Corn spurry	*Spergula arvensis* L.			P
Marsh hedge-nettle	*Stachys palustris* L.	P		
Chickweed	*Stellaris media* (L.) Cyrill.	P		P
Dandelion	*Taraxacum officinale* Weber	P	P	P
Stinkweed	*Thlaspi arvense* (L.) Scop.	P	P	P
Alsike clover	*Trifolium hybridum* L.	P	P	P
Red clover	*Trifolium pratense* L.	P	P	P
White clover	*Trifolium repens* L.		P	
Wheat	*Triticum aestivum* L.	P	P	
Common nettle	*Urtica dioica* L.	P	P	
American vetch	*Vicia americana* Mulh	P	P	P
Violet	*Viola* spp.			P

Table B.2 Vegetation surrounding research plots in 1998.

Common Name	Scientific Name	Tawayik Lake	Oster Lake	Ellerslie
Common yarrow	*Achillea millefolium* L.	P	P	
Agrimony	*Agrimonia striata* Michx.	P		
Fairy candelabra	*Androsace septentrionalis* L.	P	P	
Pussytoes	*Antennaria parvifolia* Nutt.		P	
Showy aster	*Aster conspicuus* Lindl.		P	
Smooth aster	*Aster laevis* L.	P	P	
Slough grass	*Beckmannia syzigachne* (Steud.) Fern.		P	
Smooth brome	*Bromus inermis* L.		P	
Shepherd's purse	*Capsella bursa-pastoris* (L.) Medic	P		
Water sedge	*Carex aquatilis* Wahlenb.		P	
Sedge	*Carex* spp.		P	
Mouse-eared chickweed	*Cerasium vulgatum* L.		P	
Lamb's quarters	*Chenopodium album* L.	P	P	
Strawberry blite	*Chenopodium capitatum* (L.) Aschers.	P	P	
Maple-leaved goosefoot	*Chenopodium gigantospermum* Aellen	P		
Canada thistle	*Cirsium arvense* (L.) Scop.	P	P	P
Collomia	*Collomia linearis* Nutt.		P	
Flixweed	*Descurainia sophia* (L.) Webb	P	P	
Fireweed	*Epilobium angustiflolium* L.	P		
Field horsetail	*Equisteum arvense* L.			
Smooth wild strawberry	*Fragaria glauca* (S. Wats.) Rydb		P	
Wild strawberry	*Fragaria virginiana* Duchesne		P	
Hemp nettle	*Galeopsis tetrahit* L.	P	P	
Northern bedstraw	*Galium boreale* L.	P		
Yellow avens	*Geum aleppicum* Jacq.		P	
White vetchling	*Lathyrus ochroleucus* Hook.		P	
Wild peavine	*Lathyrus venosus* Muhl.		P	
Puccoon	*Lithospermum* spp.		P	
Wild bergamont	*Monarda fistulosa* L.	P	P	
Plains muhly	*Muhlenbergia cuspidata* (Torr.) Rydb.	P	P	
Timothy	*Phleum pratense* L.	P	P	
Common plantain	*Plantago major* L.		P	
Fowl bluegrass	*Poa palustris* L.		P	
Kentucky bluegrass	*Poa pratensis* L.	P	P	
Prostrate knotweed	*Polygonum aviculare* L.		P	
Balsam poplar	*Populus balsamifera* L.	P	P	
Trembling aspen	*Populus tremuloides* Michx.	P	P	
White cinquefoil	*Potentilla arguta* Pursh	P	P	
Rough cinquefoil	*Potentilla norvegica* L.	P		
Wild gooseberry	*Ribes hirtellum* Michx.	P	P	
Wild red raspberry	*Rubus idaeus* L. var. *strigosus*	P	P	
Willow	*Salix* spp.		P	
Canada goldenrod	*Solidago canadensis* L.	P	P	
Prairie goldenrod	*Solidago missouriensis* Nutt.	P		
Western snowberry	*Symphoricarpos occidentalis* Hook.	P	P	
Dandelion	*Taraxacum officinale* Weber	P	P	P
Stinkweed	*Thlaspi arvense* L.	P	P	P
Alsike clover	*Trifolium hybridium* L.	P	P	
White clover	*Trifolium repens* L.	P		
Stinging nettle	*Urtica dioica* L.	P	P	
American vetch	*Vicia americana* Muhl ex. Willd	P	P	
Early blue violet	*Viola adunca* J.E. Smith		P	

Table B.3 Weeds and other seeds in seed mix.

Common name	Scientific name
Common yarrow	*Achillea millefolium* L.
Mustard	*Brassica* spp.
Bromegrass	*Bromus* spp.
Shepherd's purse	*Capsella bursa-pastoris* (L.) Medic
Sedge	*Carex* spp.
Hawksbeard	*Crepis* spp.
Rough fescue spp.	*Festuca* spp.
Hooker's oat grass	*Helictotrichon hookeri* (Scribn.) Henr.
Sweet clover	*Melilotus* spp.
Timothy	*Phleum pratense* L.
Plantain	*Plantago* spp.
Kentucky bluegrass	*Poa pratensis* L.
Cinquefoil	*Potentilla* spp.
Annual sow-thistle	*Sonchus oleraceus* L.
Alsike clover	*Trifolium hybridium* L.

APPENDIX C DETAILED DESCRIPTION OF RESEARCH SITES

ELLERSLIE RESEARCH STATION

The University of Alberta's Ellerslie Research Station is located on the south edge of Edmonton, Alberta (53° 27' 1" N, 113° 37' 56" W) in the Aspen Parkland Ecoregion (Strong and Leggat 1992). This area is the climatic and ecological transition zone between the boreal forest and grassland areas, and covers about 8% of Alberta. The area is defined as a mixture of Black and Dark Gray Chernozemic soils and a mix of native grassland and deciduous forest communities forming a parkland.

The Research Station is located in the southern half of the Interior plain, which consists of sedimentary bedrock covered by a thick mantle of glacial drift and underlain by crystalline Precambrian rocks (Crown 1977). The bedrock is of Edmonton Formation, which is an upper cretaceous brackish water formation of bentonitic sandstones, sandy shales, bentonitic clays and coal seams (Bowser et al. 1962, Crown 1977). The Laurentide ice sheet covered the area and upon its retreat left a mantle of till consisting of material of local origin and material transported over long distances (Bowser et al. 1962).

The topography at the Ellerslie Research Station is level to gently rolling (Bowser et al. 1962). All sites for this research are located on relatively level terrain. The area has fairly well to well-drained soil (Bowser et al. 1962). The Ellerslie area eventually drains into the North Saskatchewan River system. The Station is located on Malmo silty clay loam soil, which is an Eluviated Black Chernozem (Bowser et al. 1962). The parent material is slightly saline, fine textured Lacustrine material over glacial till.

Ellerslie Research Station has a continental climate (Bowser et al. 1962). It is located in the prairie-boreal climatic region (Strong and Leggat, 1992). Average summer temperature for the area is 14.4 °C, and ranges from 7.7 to 20.9 °C. Average winter temperature is -8.7 °C, and ranges from -14 to -3.7 °C. Mean annual temperature is 3.3 °C. Total annual precipitation averages 412 mm, with 259 mm falling through the summer. Maximum precipitation falls in July rather than June as it does in the grassland ecoregions. The climate in this area is influenced by the mid-Alberta storm track. The aspen parkland has more days with measurable precipitation than grassland regions. Winter precipitation amounts are similar to the mixed grass ecoregion, but snow cover

tends to remain longer in the Aspen Parkland due to colder temperatures, less wind and fewer chinooks. The area typically receives less than 15 chinook days per winter. Summer evapotranspiration is lower than other grassland regions, with monthly averages of -50 mm. An average of 1257 growing degree days occur annually in this area. The Aspen Parkland is warmer than the Low Boreal Mixedwood ecoregion during both summer and winter, and is slightly wetter in the summer.

The Station historically was covered by aspen parkland, a mix of grassland and trembling aspen (*Populus tremuloides* Michx.) clones (Strong and Leggat, 1992). The grassland community was a mix of rough fescue (*Festuca hallii* (Vasey) Piper), bluebunch fescue (*Festuca idahoensis* Elmer), June grass (*Koeleria macrantha* (Ledeb.) J.A. Schultes f.), needle grasses (*Stipa* spp.), three flowered avens (*Geum triflorum* Pursh), sticky purple geranium (*Geranium viscosissimum* Fisch. & Mey.) and northern bedstraw (*Galium boreale* L.). Shrub communities dominated by saskatoon (*Amelanchier alnifolia* Nutt.), prickly rose (*Rosa acicularis* Lindl.), buckbrush (*Symphoricarpos occidentalis* Hook.), snowberry (*Symphoricarpos albus* (L.) Blake) and silver willow (*Elaeagnus commutata* Bernh.) are found in moist areas. Trembling aspen, along with saskatoon and willows (*Salix* spp.), form the major tree component in the community. Veiny meadow rue (*Thalictrum venulosum* Trel.), northern bedstraw, wild strawberry (*Fragaria virginiana* Dcne), prickly rose and fireweed (*Epilobium angustifolium* L.) are present in the understory. Prior to European settlement the area was dominated by grassland (Strong and Leggat 1992). Since the extermination of bison and control of wildfires, aspen has become more prevalent (Bailey and Wroe 1974, Anderson and Bailey 1980). The site at the Ellerslie Research Station has been used for agricultural research for the past ten years, using a crop fallow rotation.

Elk Island National Park

Oster Lake and Tawayik Lake are located in Elk Island National Park (53° 37' 30" N, 112° 55' 10" W and 53° 36' 37" N, 112° 53' 41" W respectively). Elk Island National Park is located 37 km east of Edmonton along Highway 16 in the Beaver Hill Upland, in the Low Boreal Mixedwood Ecoregion (Strong and Leggat 1992). This region was previously classed as part of the Dry Subregion of the Boreal Mixedwood. The area is a

transition zone between Aspen Parkland and Low Boreal Mixedwood Ecoregions. Monthly temperatures are similar to Aspen Parkland, but the area gets more precipitation with plants and soils more typical of the Low Boreal Mixedwood Ecoregion.

The Park is located in the southern half of the Interior plain, which consists of sedimentary bedrock covered with a thick mantle of glacial drift and underlain by crystalline Precambrian rocks (Crown 1977). The bedrock is Edmonton Formation, which is an upper cretaceous brackish water formation made of bentonitic sandstones, sandy shales, bentonitic clays and coal seams (Bowser et al. 1962, Crown 1977). The Laurentide ice sheet covered this area and left a mantle of till, consisting of material of local origin and material transported over long distances (Bowser et al. 1962).

Elk Island National Park is located at the north end of the Cooking Lake Moraine, which is a hummocky disintegration moraine. The Park in general has knob and kettle topography, with numerous sloughs and peaty depressions (Bowser et al. 1962, Crown 1977). The topography is undulating to hilly (Bowser et al. 1962, Crown 1977). Most upland soils are moderately well to well drained (Bowser et al. 1962, Crown 1977). The area has the deranged surface drainage pattern associated with its moraine (Crown 1977). Most surface drainage is through low-lying organic areas. The soils have a relatively low infiltration rate and permeability. Soils consist of 75% Cooking Lake Loam, 10% Uncas Loam, and 15% sloughs and organic soils (Bowser et al. 1962). Cooking Lake Loam is an Orthic Gray Luvisolic soil developed mainly under forest vegetation on till parent material mainly of Edmonton formation. Some stones occur in the profile. The soil has a mild suggestion of being Solonetzic. Uncas Loam, found mainly where the topography is more rolling, is an Orthic Dark Gray Chernozemic soil developed on till parent material. Stones can be found throughout the profile. The area west of Tawayik Lake, an aspen-grassland area, has a high proportion of Dark Gray Chernozemic soils, while Oster Lake is mainly Orthic Gray Luvisolic soil (Crown 1977). The surface soil around the lakes, developed from glaciolacustrine sediments, is silt loam to silty clay loam texture. The Orthic Gray Luvisols have strongly developed Ae over Bt horizons. The Dark Gray Chernozems have an Ah horizon over the Ae and Bt horizons.

Elk Island National Park has a continental climate, with warm summers and warm winters (Crown 1977). It is located in the boreal climatic region (Strong and Leggat,

1992). Average summer temperature is 13.8 °C, and ranges from 7.0 to 20.4 °C. Average winter temperature is –10.5 °C, and ranges from –15.8 to –5.3 °C. Mean annual temperature is 0.8 °C. The frost-free period here tends to be shorter than in the Aspen Parkland, and summer temperatures are slightly cooler. This results in about 20% fewer growing degree days. Total annual precipitation for this area is 380 mm, with 235 mm falling in summer. Maximum precipitation falls in July, with June a close second. Winters in this region tend to be colder than the aspen parkland and grassland ecoregions. Snow cover in winter is uniform since wind is not a major factor for redistribution.

In Elk Island National Park, the Oster Lake area is dominated by trembling aspen with balsam poplar (*Populus balsamifera* L.) found in wetter sites (Crown 1977). The area has a dense shrub layer. Some white birch (*Betula papyrifera* Marsh.) and white spruce (*Picea glauca* (Moench) Voss) can be found in the oldest stands (Strong and Leggat 1992). The Tawayik Lake area is more open with areas of grassland mixed with aspen stands (Crown 1977). Aspen forests typically dominate the Boreal Mixedwood Ecoregion (Strong and Leggat 1992). The understory includes bluejoint (*Calamagrostis canadensis* (Michx.) Beauv.), cream-colored vetchling (*Lathyrus ochroleucus* Hook.), prickly rose, bunchberry (*Cornus canadensis* L.), willows, and saskatoon. Drier areas and those with more saline soils develop vegetation similar to the Aspen Parkland.

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APPENDIX D DETAILED DESCRIPTION OF NATIVE FORB SPECIES USED IN THIS RESEARCH

Common yarrow (*Achillea millefolium* L.)

Common yarrow is a native cool season perennial forb found in grasslands and open woods (Gerling et al. 1996). It is an aggressive plant, spreading by both seeds and creeping roots. In cultivated sites, it can form mats up to 60 cm in diameter (Currah et al. 1983). Common yarrow has numerous aromatic fern-like basal leaves, which are gray-green, finely divided and wooly. It forms numerous white flower heads in a compound corymb, which can be flat or round topped (Stubbendick et al. 1993). The plants grow 30 to 80 cm tall (Gerling et al. 1996, Pahl and Smreciu 1999). Common yarrow seed is about 2 mm long, oblong and flattened, with 5500 to 6100 seeds per gram (Currah et al. 1983, Pahl and Smreciu 1999). Currah et al. (1983) found common yarrow produces large quantities of seed with an average germination of 18 to 28%. They recommended moist-cold stratification, which increases germination to 59 to 69%. However, Pahl and Smreciu (1999) found that seed had a germination rate of 99%. They recommend placing seed on the soil surface, since light enhances germination. Taylor and Hamlin (1963) also found plants established easily by seed. Stevens et al. (1996) recommended seeding on the surface or to a maximum depth of 0.2 cm. They also found fall seeding gave best establishment, unless soil moisture was adequate for establishment in spring. Common yarrow is actively mycorrhizal (Currah et al. 1983). Its habitat includes prairies, roadsides, aspen woodlands, parklands, boreal forest and Rocky Mountains (Looman and Best 1994). It grows from Alaska and the Yukon east to north Hudson Bay, northern Quebec and Newfoundland (Moss 1992). It is an early colonizer of disturbed sites and a component of later seres (Gerling et al. 1996). It may be grazed when young and green, but has poor forage value for domestic livestock and wildlife (Stubbendick et al. 1993).

Long-fruited anemone (*Anemone cylindrica* A. Gray)

Long-fruited anemone is an erect perennial forb found in grasslands and dry open woods through the prairies, parkland and foothills (Currah et al. 1983, Gerling et al. 1996). It grows from British Columbia east to southwestern Quebec and south to Arizona, New Mexico, Kansas, Missouri and New Jersey (Moss 1992). The plants are

usually solitary and have a woody, branching taproot (Currah et al. 1983). Leaves are basal, petioled and deeply five parted. The white flowers are 1 to 2 cm across and each develop into a wooly, white cylindric head of achenes. The stems grow 20 to 80 cm tall. Long-fruited anemone flowers in June, seeds ripen from July to early August and plants often die back in September. It produces numerous seeds with germination of 56 to 66% (Currah et al. 1983). Moist-cold stratification increases germination to 60 to 87%. Seed size is 110 seeds per gram (Currah et al. 1983). Long-fruited anemone is an early seral species (Gerling et al. 1996). It has poor forage value for livestock (Gerling et al. 1996).

Smooth aster (*Aster laevis* L.)

Smooth aster is a warm season perennial forb found in grasslands, roadsides and open woodlands (Looman and Best 1994). It grows in open, generally dry areas from British Columbia east to Ontario and southern Quebec, and south to Washington, New Mexico, Kansas, Missouri, Georgia and Connecticut (Moss 1992). It spreads both by seed and rhizomes, growing 40 to 100 cm tall. It can form clumps up to 40 cm in diameter (Currah et al. 1983). The narrow, alternate leaves are 10 to 13 cm long (Currah et al. 1983). The inflorescence is a loose, panicle-like arrangement of many 2 to 3 cm heads. The ray flowers are blue to purple with yellow disc flowers. The seed is a tan to brown elliptical achene, 3 mm long, with a white, bristly papus. Currah et al. (1983) found seed germination was good and no treatment was necessary. Smooth aster flowers from July to September and seeds ripen in September and October. It is actively mycorrhizal (Currah et al. 1983) and provides good forage for wildlife and domestic livestock (Gerling et al. 1996). It is found in both early and late seral stages (Gerling et al. 1996). Plants have a fibrous root system with numerous rhizomes (Currah et al. 1983). It produces numerous seeds that have good germination.

Harebell (*Campanula rotundifolia* L.)

Harebell is a short-lived perennial found in grasslands, parklands and foothills across Alberta (Cormack 1977). It grows in dry meadows, hillsides and open woods to alpine elevations from Alaska, Yukon Territory, the southwest part of the District of Mackenzie east to James Bay, northern Quebec and Newfoundland south to California,

New Mexico, Texas, Nebraska, Iowas, Pennsylvania and New Jersey (Moss 1992). The inflorescence consists of three to four bell-shaped flowers, 1 to 2 cm long and purplish blue in color (Currah et al. 1983, Johnson et al. 1995). It has slender stems, 20 to 40 cm tall, with thin, linear stem leaves. The basal leaves are long-stalked and egg to heart shaped. Harebell has mainly fibrous roots but also a slender taproot and rhizomes (Currah et al. 1983, Johnson et al. 1995). Seeds are elliptical and 1 to 1.5 mm long (Pahl and Smreciu 1999). Seed weight is 1530 to 2640 seeds per gram. It produces large quantities of seeds with good germination (Currah et al. 1983). Germination averages 82%, but moist-cold stratification will increase it (Currah et al. 1983, Pahl and Smreciu 1999). Harebell self-sows readily and establishes easily (Taylor and Hamblin 1963). Pahl and Smreciu (1999) recommend surface to very shallow seeding. Harebell emerges early in the season, flowers from June through September and seed matures from August to October. It is actively mycorrhizal (Currah et al. 1983). It is common in late seres, spreads rapidly on sites with limited competition and is recommended for reclaiming stony or shallow soils (Pahl and Smreciu 1999).

Blanket flower (*Gaillardia aristata* Pursh)

Blanket flower is a short-lived, cool season perennial found in prairie grasslands and open woods (Gerling et al. 1996). It can be found in dry, open areas, especially disturbed sites, and will often persist in small amounts in later seral stages. Blanket flower grows from British Columbia to Manitoba, and south to Oregon, Utah, Colorado and South Dakota (Moss 1992). It tends to be an aggressive plant (Gerling et al. 1996). Blanket flower has a short, slender taproot with numerous fibrous roots. It forms clumps up to 40 cm in diameter, larger without competition (Currah et al. 1983). The leaves are alternate, 5 to 12 cm long, gray-green and puberulent (Currah et al. 1983). The plants grow 20 to 60 cm tall. The inflorescence is a solitary radiate head 3 to 7 cm across. The ray flowers are yellow-orange with a purple base. The disk flowers are purple-brown. The seed is a gray to black, conical achene, 3 to 4 mm long, covered in dense bristles with a pappus of five to ten papery bristles (Pahl and Smreciu 1999). Seed weight is 345 to 457 seeds per gram (Pahl and Smreciu 1999). Currah et al. (1983) found that seed germination ranged from 45 to 90%, and was extremely variable depending on field

collection. Pahl and Smreciu (1999) found germination averaged 70%, and recommend surface to very shallow seeding. No seed treatment is recommended (Currah et al. 1983, Pahl and Smreciu 1999). Blanket flower blooms in July and August, and seeds ripen from late July to September (Currah et al. 1983). It is actively mycorrhizal. It is an early seral species and provides poor forage for livestock (Gerling et al. 1996).

Three flowered avens (*Geum triflorum* Pursh)

Three flowered avens, or prairie smoke, is a cool season perennial forb found in grasslands, clearings and open woods in mixed prairie and fescue grasslands (Gerling et al. 1996, Pahl and Smreciu 1999). It grows from the south part of the District of Mackenzie, through British Columbia east to Newfoundland, and south to California, Nevada, Utah, New Mexico, South Dakota, Iowa, Illinois and New York (Moss 1992). It has both fibrous roots and rhizomes and can form clumps up to 30 cm in diameter (Currah et al. 1983). The mostly basal leaves are 15 to 20 cm long, compound pinnate, dark green and softly pubescent. The inflorescence is a three (one to five) flowered cyme on a 20 to 40 cm stalk. The flowers are ureolate, often nodding, with five cream-yellow colored petals. The sepals are red to purple in color. The seed is a 2 to 3 mm long pear-shaped achene (Pahl and Smreciu 1999). The seed surface is covered with silky hairs, and the seed has a persistent feathery style 7 to 9 mm long. Seed size is 1400 to 2000 seeds per gram. Currah et al. (1983) found that plants produce many seeds that have 78 to 97% germination. Moist-cold stratification increased germination to 97 to 100%. Pahl and Smreciu (1999) found seed germination averaged 93% without stratification and recommend seeding on the soil surface or very shallow. Three flowered avens is actively mycorrhizal (Currah et al. 1983) and provides poor forage for livestock (Gerling et al. 1996). It is part of early and later grassland seral stages (Pahl and Smreciu 1999).

Wild blue flax (*Linum lewisii* Pursh)

Wild blue flax is an erect short-lived perennial forb found in grasslands, dry open woods, parklands, foothills and montane slopes (Gerling et al. 1996, Pahl and Smreciu 1999). It is found in the mixed prairie and fescue prairie, but is less common in aspen parkland (Pahl and Smreciu 1999). It grows from Alaska, the Yukon, Victoria Island and

the western District of Mackenzie to James Bay, and south to California, New Mexico, Texas, Oklahoma, Wisconsin and the Great Lakes (Moss 1992). It spreads aggressively by seed. The plants generally grow singly and may be up to 30 cm in diameter (Currah et al. 1983). The leaves are alternate, linear, 1 to 2 cm long and gray-green in color (Currah et al. 1983). The inflorescence is a terminal corymb of several 2 to 3.5 cm blue flowers. Wild blue flax blooms in June and July and seeds mature in July through September (Pahl and Smreciu 1999). Stems grow 20 to 70 cm tall. The seeds are 4 to 5 mm long, dark brown to black and a flattened teardrop shape (Currah et al. 1983, Pahl and Smreciu 1999). Seed size ranges from 602 to 645 seeds per gram (Pahl and Smreciu 1999) and up to 800 seeds per gram (Currah et al. 1983). Currah et al. (1983) found plants produce many seeds with germination of 60 to 84%. Germination was best at soil temperatures of 12 to 15 °C. Moist-cold stratification increased germination only to 73 to 85%. Pahl and Smreciu (1999) found germination averaged 73% and did not recommend pretreatment. They recommend this species be seeded on the soil surface or very shallow. Stevens et al. (1996) recommend seeding wild blue flax no more than 0.2 to 0.3 cm deep. They also recommend fall seeding to allow a small seed crop the first growing season. Wild blue flax is actively mycorrhizal and has deep fibrous roots (Currah et al. 1983). It is an early seral species, but will persist in small amounts in later seral stages (Pahl and Smreciu 1999). It provides poor forage for livestock (Gerling et al. 1996).

Hoary puccoon (*Lithospermum canescens* (Michx.) Lehm.)

Hoary puccoon is a softly hairy, gray-green perennial growing 15 to 50 cm tall (Looman and Best 1979) from a large, woody tap root (Taylor and Hamblin 1963). The leaves are linear and 1 to 4 cm long. The orange-yellow tubular flowers are found in a compact cluster at the top of the plant (Looman and Best 1979) and appear in July (Taylor and Hamblin 1963). Hoary puccoon is found in the eastern and northern parts of the parkland (Vance et al. 1984). Taylor and Hamblin (1963) recommend propagating this species from seeds sown in early spring.

Wild bergamot (*Monarda fistulosa* L.)

Wild bergamot is a warm season perennial forb found in open woods, thickets and

grasslands, often on north-facing slopes (Looman and Best 1994). It grows from British Columbia east to Quebec, and south to Arizona, New Mexico, Texas, Louisiana, Alabama and Georgia (Moss 1992). It spreads aggressively by seed and rhizomes. Wild bergamot has gray-green opposite leaves, 2.5 to 7.5 cm across (Currah et al. 1983). The stems grow 20 to 70 cm tall (Currah et al. 1983). The plant is strongly scented. The flower is a pink or lilac terminal globose, head-like cluster, 2.5 to 4 cm across. Seeds are smooth, oblong, brown nutlets with large basal depressions (Currah et al. 1983). Currah et al. (1983) found that germination was between 68 and 90% and was not improved by moist-cold stratification. Taylor and Hamblin (1963) report that it can be propagated from seeds sown at any time. Seed size is 3300 seeds per gram (Currah et al. 1983). Wild bergamot blooms in July and August, and the seeds ripen in August and September. It is actively mycorrhizal (Currah et al. 1983, Gerling et al. 1996). Forage value for livestock is poor. It is an early seral species (Gerling et al. 1996).

Purple prairie clover (*Petalostemon purpureum* (Vent.) Rydb.)

Purple prairie clover is a long lived, warm season perennial forb found on prairie grasslands, eroded slopes and dry banks on the mixed prairie and fescue prairie (Gerling et al. 1996, Pahl and Smreciu 1999). It grows from Alberta to western Ontario and south to New Mexico, Texas, Arkansas and Alabama (Moss 1992). It spreads only by seed and forms a very deep taproot with few lateral roots (Currah et al. 1983). The compound leaves usually have five leaflets, each 5 to 20 mm long. The inflorescence is a dense, many-flowered terminal cylindric spike, 1 to 3 cm long. The flowers are tiny and red to purple in color. Stems grow 30 to 80 cm long (Currah et al. 1983). The seeds are kidney shaped, 2 mm long and olive green to brown (Pahl and Smreciu 1999). Seed size is 290 to 550 seeds per gram (Currah et al. 1983, Pahl and Smreciu 1999). It blooms from June to August, seeds mature in August and September (Pahl and Smreciu 1999). Pahl and Smreciu (1999) found seed germination averaged 98% without pretreatment, and recommend seeding at a depth of 0.6 cm. Currah et al. (1983) found seed germination was 45 to 54%, but increased to 95 to 97% with scarification by hot water. Purple prairie clover plants occur singly in the landscape (Currah et al. 1983). They are actively mycorrhizal and form associations with rhizobial bacteria to fix atmospheric nitrogen

(Currah et al. 1983). Purple prairie clover is an early seral species and colonizes disturbances, especially on sandy and gravel soils (Pahl and Smreciu 1999). It is also an important component in later seral stages on grasslands. It provides excellent forage for both livestock and wildlife (Stubbendick et al. 1993).

Prairie coneflower (*Ratibida columnifera* (Nutt.) Woot. & Standl.)

Prairie coneflower is a warm season perennial forb found in dry grasslands (Gerling et al. 1996). It is common on dry to moist grasslands, roadsides, other disturbances, mixed praire, fescue prairie and occasionally aspen parkland and montane areas (Pahl and Smreciu 1999). It grows from British Columbia east to Manitoba and south to California, Texas and Arkansas (Moss 1992). It spreads by seed, can be short lived (Pahl and Smreciu 1999) and forms a taproot with many fibrous roots (Stubbendick et al. 1993). Plants occur singly, and may form clumps up to 25 cm in diameter under cultivation (Currah et al. 1983). It grows a few to several stems, 30 to 60 cm tall (Pahl and Smreciu 1999). It has 5 to 10 cm alternate leaves, pinnately divided and gray-green in color (Currah et al. 1983). The flower is solitary and forms a columnar radiate head on a long peduncle. The disk flowers can be gray-yellow to purple. The few ray flowers are 1 to 3 cm long, yellow, and reflexed. The seed is a 2 mm long, grey-black, slightly flattened achene with a pappus crown of small grey scales and one or two prominent pappus teeth (Pahl and Smreciu 1999). Seed size is 3000 seeds per gram (Currah et al. 1983, Pahl and Smreciu 1999). Pahl and Currah (1999) found seed germination averaged 68%, and was not improved by pretreatment (Currah et al. 1983). They recommend seeding on the soil surface or very shallow. Plants are prolific seed producers, but many seeds do not fill in the wild (Currah et al. 1983, Pahl and Smreciu 1999). It blooms from July to September and seed matures in late August through September (Pahl and Smreciu 1999). It is actively mycorrhizal (Currah et al. 1983, Pahl and Smreciu 1999). It provides fair to good forage for sheep and wildlife, and fair forage for cattle (Currah et al. 1983, Stubbendick et al. 1993). Prairie coneflower is an early seral species (Gerling et al. 1996) and common colonizer of disturbances (Pahl and Smreciu 1999).

Canada goldenrod (*Solidago canadensis* L.)

Canada goldenrod is a robust long-lived perennial warm season forb found in dry prairies, hillsides and open woods (Gerling et al. 1996). It does best in more mesic areas, and can be found in clearings, open woods, sheltered slopes, and roadsides in the mixed prairie, fescue grasslands, aspen parkland, boreal and montane areas (Pahl and Smreciu 1999). It grows from Alaska, the Yukon and southwest District of Mackenzie east to Hudson Bay and Newfoundland and then south to California, New Mexico, Texas and Florida (Moss 1992). It spreads aggressively from both seeds and creeping rhizomes. The many leaves are crowded on the stems and are narrowly lance shaped, saw toothed and hairy (Currah et al. 1983). The stems range from 30 to 100 cm tall (Pahl and Smreciu 1999). The flowers are found in many small heads in a dense pyramidal terminal cluster. Both ray flowers and disc flowers are yellow. Seeds are tan to brown hairy achenes, with a papus of fine white hairs (Pahl and Smreciu 1999). Seed size is 2000 seeds per gram (Pahl and Smreciu 1999). Pahl and Smreciu (1999) found seed germination was 78%. They also found that seeds harvested after a frost might acquire secondary dormancy. The seeds may also need an after-ripening period. They recommend moist-cold stratification for dormant seed lots. Stevens et al. (1996) recommend seeding on the surface, to a maximum depth of 0.6 cm deep. They recommend either spring or fall seeding for good establishment. They found that Canada goldenrod generally set seed in the second growing season. It flowers in July and August, and seeds mature from late August through October (Pahl and Smreciu 1999). Canada goldenrod is an early seral species (Gerling et al. 1996). It provides rapid cover and is quite persistent (Pahl and Smreciu 1999). Canada goldenrod is considered poor forage for livestock (Gerling et al. 1996), but is browsed by elk and mule deer (Pahl and Smreciu 1999).

Low goldenrod (*Solidago missouriensis* Nutt.)

Low goldenrod is a warm season perennial forb found in grasslands and open woods in the prairies and southern parklands (Gerling et al. 1996). It is often found on sandy and gravelly soils (Currah et al. 1983). It grows from British Columbia east to Ontario, and south to Washington, Arizona, New Mexico, Texas, Arkansas, Oklahoma

and Tennessee (Moss 1992). It spreads aggressively from both seeds and rhizomes. The leaves are alternate, narrowly oblanceolate and 2 to 10 cm long (Currah et al. 1983). The stems and leaves are often reddish. The inflorescence is a compact terminal panicle-like arrangement of heads containing 10 to 20 flowers. Both the ray flowers and disk flowers are golden yellow. It flowers from June through August (Currah et al. 1983). The seed is a hairy achene. Currah et al. (1983) recommends moist-cold stratification to improve germination. Prairie goldenrod has a fibrous root system with rhizomes. It is an early seral species (Gerling et al. 1996). Prairie goldenrod forms small clumps in natural areas and larger colonies under cultivation (Currah et al. 1983). It provides good forage for wildlife, but poor forage for livestock although they will graze it in spring and early summer (Currah et al. 1983, Stubbendick et al. 1993, Gerling et al. 1996).

Wild vetch (*Vicia americana* Muhl.)

Wild vetch is a long-lived perennial cool season forb found in open woods, meadows, grasslands, abandoned land and disturbed areas in the mixed prairie, fescue prairie, aspen parklands and mixed woods (Gerling et al. 1996, Pahl and Smreciu 1999). It grows from southeastern Alaska, western District of Mackenzie through Saskatchewan, Manitoba and the Great Lakes, south to California, New Mexico, Texas, Oklahoma, Missouri, Ohio and the Gaspe (Moss 1992). The stems grow 30 to 100 cm tall and are climbing or trailing (Currah et al. 1983). The compound leaves are alternate, with 8 to 14 leaflets, and tendrils at the end (Johnson et al. 1995). The inflorescense is a lax raceme of 2 to 9 flowers, each about 2 cm long, and reddish purple in color (Currah et al. 1983). The seeds are 4 to 5 mm long, spherical to elliptic shaped, smooth and black to olive green in color (Pahl and Smreciu 1999). Seed size is 60 to 86 seeds per gram (Pahl and Smreciu 1999). Pahl and Smreciu (1999) found that germination averaged 78%, and recommend scarifying dormant seed lots. They also suggest seeding at 1 cm deep. Currah et al. (1983) found the species had good seed germination. American vetch has both fibrous and creeping roots (Johnson et al. 1995, Pahl and Smreciu 1999). The plants are actively mycorrhizal and also associate with rhizobial bacteria, which fix nitrogen (Pahl and Smreciu 1999). American vetch provides excellent, high protein forage for both wildlife and livestock (Gerling et al. 1996). It occurs in both early and late seral

stages and helps control erosion (Gerling et al. 1996).

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